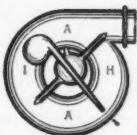


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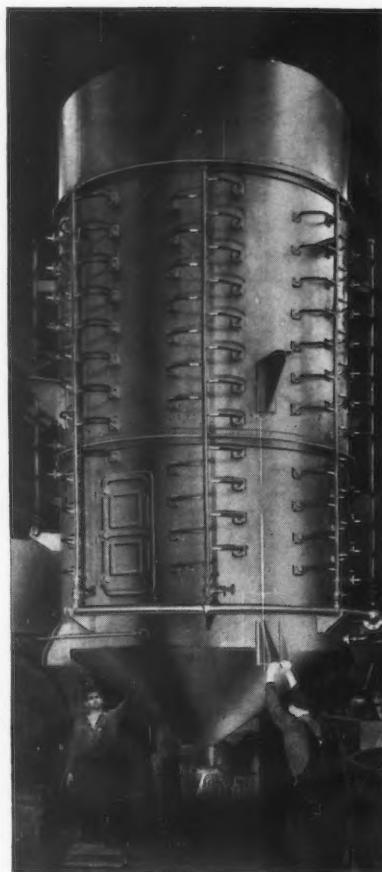
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# Concepts in Fabric Air Filtration

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FABRIC air filters offer a potentially valuable combination of low cost and high efficiency air pollution control equipment. Little information, however, is available regarding air filtration as it occurs within commercial-scale equipment. To be sure, operating data are relatively well-known for such installations, and, based on the premise that "what worked there will also work here", an engineer can select, on an experience basis alone, equipment designs and operating conditions which will produce satisfactory results in most instances. But the question arises, "Are these design and operating standards which have been evolved over the years the best standards to use today, or could they be improved to reduce capital costs, equipment sizes, or operating and maintenance expenditures, thereby making high efficiency pollution control feasible in areas where it is now impossible or, at best, a marginal operation?" To answer this question, sound engineering investigation and analysis are required.

In 1958 a new technique for fabric filter evaluation involving measurement of local filter velocities and local dust masses was proposed by the authors.<sup>1</sup> Use of this technique has led to the concepts of "filter resistance" and "permeability" which are presented here.

## Filter Resistance

In the air filtration field, the term resistance has commonly been synonymous with pressure differential between the clean-air side and the dirty-air side of a baghouse. It follows from such a concept that the resistances of all bags within a unit are identical, and that the resistance of every area on a single filter bag is the same as that of every other area. It also means that the resistance of a baghouse filtering one material is the same as the resistance of any other baghouse of any size, filtering any material at any filter velocity, so long as the pressure differences across the units are the same.

To the engineer accustomed to thinking of resistance as a property of a system measuring opposition to flow through it, pressure differential

falls short as a representation of resistance. Its use ties resistance directly to flow rate and leads to the inconsistency that simply by reducing the flow to zero the resistance of the flow system vanishes.

A direct proportionality between pressure differential and fluid velocity in the viscous flow region has long been accepted. Equations proposed for viscous flow through porous media include:

Chilton-Colburn<sup>2</sup>

$$u_f = \frac{g_c F_a}{J} \frac{1}{32 \mu} D_{pe}^2 \frac{\Delta P}{L} \quad (1)$$

Fair-Hatch<sup>3</sup>

$$u_f = \frac{g_c}{J} \frac{1}{K_{F\&H}} \frac{\alpha^3}{(1-\alpha)^2} \frac{1}{\mu} \left( \frac{V_p}{A_p} \right)^2 \frac{\Delta P}{L} \quad (2)$$

Hatch<sup>4</sup>

$$u_f = \frac{g_c}{J} \frac{1}{K_H} \frac{1}{\mu} D_c^2 \frac{\Delta P}{L} \quad (3)$$

Kozeny<sup>5</sup>

$$u_f = \frac{g_c}{J} \frac{C_K}{g_L} \frac{\alpha^3}{(1-\alpha)^2} \frac{1}{\mu} \left( \frac{V_p}{A_p} \right)^2 \frac{\Delta P}{L} \quad (4)$$

Choosing the Kozeny equation as an example, it is seen that the ratio of pressure differential to velocity, constant for a bed of fixed configuration, is

$$\frac{\Delta P}{u_f} = J \frac{g_L}{g_c} \frac{\mu L}{C_K} \left( \frac{A_p}{V_p} \right)^2 \frac{(1-\alpha)^2}{\alpha^3} \quad (5)$$

That is, this ratio is a function of fluid viscosity,  $\mu$ , cake thickness,  $L$ , cake porosity (ratio of void volume to total or bulk volume of cake),  $\alpha$ , and the ratio of particle surface area to particle volume,  $(A_p/V_p)$ .

For a particular fluid flowing such as air, this ratio,  $(\Delta P/u_f)$ , is a definite property of a filter medium. This term then, does represent a property of a flow system and is directly analogous to the resistance of an electrical circuit.

A tubular filter and its electrical analog are

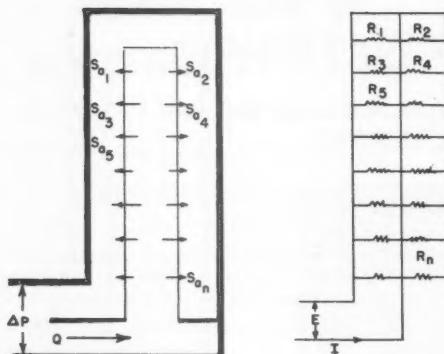


FIGURE 1. Electrical analogy for filter flow system.

shown in Figure 1. Ohm's Law applies to the circuit as follows:

$$I = \frac{E}{R_e} \quad (6)$$

where,

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \quad (7)$$

Similarly, one may write,

$$Q = \frac{\Delta P}{S_e} \quad (8)$$

In other words a flow rate,  $Q$ , is caused by the driving force,  $\Delta P$ , acting across an effective resistance,  $S_e'$ . It is important to re-emphasize here that  $\Delta P$ , even though conventionally referred to as filter resistance, is not a resistance at all, but is, in reality, a driving force. To avoid confusion it has been helpful to refer to  $S_e'$  as the  $S$ -factor, which, upon substitution of the average filter velocity—filter area product for  $Q$  in equation (8) is defined by

$$S_e' = \frac{\Delta P}{(u_{f_{avg}})(A_f)} \quad (9)$$

In terms of the units most often used,  $S_e'$  will have the dimensions, (inches  $H_2O$ )/(fpm)(ft $^2$ ). If the  $S$ -factor is arbitrarily referred to one square foot of filter area, then

$$S_e = \frac{\Delta P}{(u_{f_{avg}})} \quad (10)$$

and the units of  $S_e$  become (inches  $H_2O$ )/(fpm).

When considering an incremental filter area, the local  $S$ -factor (resistance) is simply

$$S = \frac{\Delta P}{u_f} \quad (11)$$

As in an electrical circuit, the effective resistance of the entire flow system (a filter bag such as in Figure 1, or an entire baghouse, etc.) is composed of local  $S$ -factors combined as follows:

$$\frac{1}{S_e} = \frac{1}{S_1} \left( \frac{a_1}{A_f} \right) + \frac{1}{S_2} \left( \frac{a_2}{A_f} \right) + \frac{1}{S_3} \left( \frac{a_3}{A_f} \right) + \dots + \frac{1}{S_n} \left( \frac{a_n}{A_f} \right) \quad (12)$$

This view of an over-all resistance as a sum of many parts can contribute much to an understanding of why resistances are what they are, and can give, as well, an insight into if and how they can be reduced. The use of  $S$ -factors allows direct comparison of filter media from one filtering situation to another, regardless of filter velocity or unit size.

#### Permeability

Equations (1) through (4), as well as several others, have been shown experimentally to apply to flow through certain granular beds established under laboratory conditions. Unfortunately, however, in the field of air filtration these equations are of quite limited utility, since the only factors involved which can be satisfactorily evaluated at this time are  $\Delta P$ ,  $u_f$ , and  $\mu$ . For less fundamental application, the equation formulated by D'Arcy<sup>6</sup> in 1856 is often used:

$$u_f = K_D \frac{\Delta P}{L} \quad (13)$$

By comparison with the equations listed above, one sees that  $K_D$ , often referred to as "permeability", reflects a number of properties of the filter medium. Included are void volume, particle size and shape, surface properties, and packing characteristics. In the form of equation (13), D'Arcy's law still can not be applied since the term  $L$ , cake thickness, is present. Substituting the ratio of areal density to bulk density for cake thickness, however, gives a form which can be used:

$$u_f = K_D \rho_b \frac{\Delta P}{W} = K \frac{\Delta P}{W} \quad (14)$$

*K* may now be designated "permeability", and equation (14) may be rewritten as

$$K = \frac{W u_f}{\Delta P} = \frac{W}{S} \quad (15)$$

It is seen, therefore, that permeability, as proposed here, is simply the areal density of filter cake per unit resistance. In other words, permeability is an intensive property (independent of mass) relating directly to the matrix structure of the filter medium, while the *S*-factor is an extensive property (mass dependent) relating to the resistance of the filter medium to flow through it. While the *S*-factor will always increase as additional material is deposited on the filter cake, permeability may increase, decrease, or remain constant over the same period.

#### Layer Values

In addition to resistance and permeability of the filter medium as a whole, these properties may be calculated for the dust mass alone or for a layer of dust cake formed during a portion of the filtration period.

For the general case in which filter velocity changes during filtration, i.e., for a baghouse handling a varying air flow or for specific locations on a filter surface, resistance and permeability of dust layers must be calculated from:

$$s_{2,4} = \frac{\Delta P_4 - \Delta P_3 \left( \frac{u_{f4}}{u_{f3}} \right)}{u_{f4}} = S_4 - S_3 \quad (16)$$

$$k_{2,4} = \frac{(W_4 - W_3) u_{f4}}{\Delta P_4 - \Delta P_3 \left( \frac{u_{f4}}{u_{f3}} \right)} = \frac{W_4 - W_3}{S_4 - S_3} = \frac{w_{2,4}}{s_{2,4}} \quad (17)$$

Since permeability is an intensive property, it must be remembered that  $k_{2,4} \neq K_4 - K_3$ .

The layer value concept finds most utility in "separating" the dust mass from the fabric itself. The resistance and permeability of the dust alone can be evaluated rather than those of the combined dust mass and fabric. One must obviously not be misled into believing that a sharp physical boundary distinguishes two individual matrix structures. Once filtration has been started through a new filter, the virgin resistance and permeability of the fabric itself are lost forever, and their values can be compensated for only mathematically. Many dust particles adhering both to the external and internal surfaces of the fabric are impossible to remove by conventional cleaning methods.

This combined fabric-dust matrix is the support upon which the "pure dust cake" is formed.

Because of the vast differences among the various filter fabrics, differences resulting from weight, weave, fiber characteristics, etc., the structure of the residual dust cake, dust remaining on the fabric immediately after cleaning, will be strongly dependent upon the fabric type as well as upon the particulate matter involved. Consideration of the dust mass alone, therefore, facilitates comparison of fabric types by allowing assessment of residual permeabilities and resistances as a function of the filter fabric used.

It is apparent that other advantages are associated with the segregation of dust mass properties per se. For one thing, of greatest practical interest are the amount of dust collected and the changes in resistance and permeability of the filter medium attributable to this dust. Also, and this is perhaps the most compelling, permeability has no real meaning when singularly dissimilar materials are present. In the very transformation of D'Arcy's law into equation (15), a tacit assumption of the constancy of  $\rho_s$  is expressed. Finally, the fabric properties—its areal density, its resistance, and its permeability—can be looked upon as limits which can be approached during filter cleaning but presumably can never be reached. These, in turn, provide bases for measuring the effectiveness of various methods of cleaning.

A somewhat different motive is involved in the "separation" of one dust layer from another. Here, interest is centered about determining whether dust collected during a particular interval of the filtration period is different from dust collected during other intervals. In this case an actual physical separation of the layers is inferred, as distinguished from the mathematical separation of dust mass from filter fabric discussed previously. Two very important assumptions are now implied with the calculations of equations (16) and (17). These are (a) that no lateral flow through the filter cake occurs, and (b) that a layer of dust, once deposited, maintains the same permeability (matrix structure) throughout its life, i.e., until it is physically disturbed as during the cleaning period. The former assumption must be considered valid at all times, and for filter areas considered in practice (say greater than one square inch), there would appear to be little question but that it does hold. The latter assumption, however, is thought to be invalid in many cases. Experimental evidence has been gathered to support this conclusion and these data will be discussed in detail in a later section. Briefly, there is strong reason to believe that cake structure can change, either subtly by the continuing penetration of fine particles deeper and deeper into the matrix, or precipitously, by

sudden, irreversible shifts in matrix structure. If such changes occur in the previously existing matrix, they will be automatically attributed to the layer being considered.

#### Cake Collapse and Cake Puncture

Two phenomena related to gross structural shifting have been observed experimentally. These have been termed, descriptively, cake collapse and cake puncture. Cake collapse takes place when external forces acting on the filter cake become strong enough to overcome the frictional and adhesive forces maintaining the cake matrix in its original configuration. These external forces may be the result of static pressure differentials across the cake, kinetic energy variations and viscous drag within the cake, or extraneous physical contacts with the filter. When these forces are of sufficient magnitude, the cake structure can shift to a more compact condition and cake permeability will be reduced.

Cake puncture is said to occur when small holes are literally blown through the dust cake, causing the resistance of the cake at these points to drop to near zero compared with the resistance of other areas of the filter. Such local disintegration of the filter cake may be thought of as a more severe manifestation of the application of the

same external forces causing cake collapse. Cake puncture usually is self-repairing, since the increased flow through the area brings more dust to the vicinity of the puncture and inertial aerosol deposition mechanisms are enhanced by the higher velocity.

#### Experimental Results

Having considered certain concepts, let us now illustrate their application in the evaluation of experimental results. The work referred to was conducted during 1958 at the Air Pollution Engineering Laboratory of the U. S. Public Health Service in Cincinnati. Most of the data were obtained from the operation of a pilot-scale experimental baghouse and employing the mass and filter velocity probes<sup>1</sup> especially designed for study of the filtration process incrementally over the entire filter area.

#### Test Conditions

Considerable effort has been applied to the development of a unit which will allow full use of the previously mentioned evaluation instruments while maintaining both controlled versatility and an effective representation of a multiple-bag commercial air filter. The two-bag pilot-scale baghouse, as shown in Figure 2, consists of an air sup-

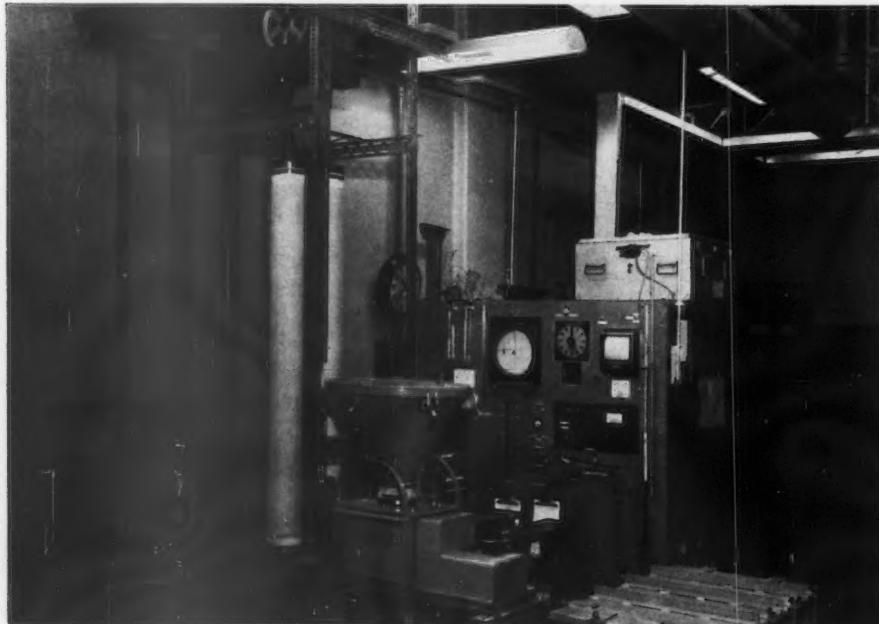


FIGURE 2. Pilot-scale experimental baghouse.

ply unit, dust feeder, disperser, air distribution hopper, test bags, and a shaker.

This baghouse was operated at the following conditions to obtain the data discussed in this report. Test dust consisted of electrically precipitated fly ash from the Cincinnati Gas and Electric Co. power station. The raw dust was elutriated to less than 7 microns. The geometric mean diameter by weight of the test dust was 3.2 microns with a standard geometric deviation of 1.8 microns. A sufficient quantity of fly ash was prepared and blended to assure availability of a uniform test dust for this entire series of experiments. The filter tubes were 6 inches in diameter by 63 inches long and were fabricated of a standard cotton sateen (National Filter Media Style No. 74, 96 warp  $\times$  60 woof, 9.7 oz/yd<sup>2</sup>) having a rated Frazier Porosity of about 15 ft<sup>3</sup>/min (i.e., volumetric flow rate through one ft<sup>2</sup> of fabric at a pressure differential of 0.5 inch H<sub>2</sub>O). In terms of resistance and permeability, the fabric would be rated at  $S_o = 0.033$  inch H<sub>2</sub>O/fpm and  $K_o = 14,300$  (grains/ft<sup>2</sup>) $^2$ /(inch H<sub>2</sub>O/fpm). The shaking action was vertical with a 2 1/4 inch amplitude at a frequency of 6.75 cps while the length of each cleaning period was one minute. Tests were conducted at average filter velocities ranging from 0.75 to 7.5 fpm, and the average filter velocity was held constant through each filtration period. Inlet dust loadings were varied from less than one to about ten grains/ft<sup>3</sup>.

#### Discussion

To demonstrate the utility of the concepts advanced, a number of examples of their use in data

analysis are cited in the following paragraphs. The complete and detailed evaluations of the research from which these examples are chosen will be published separately, and it must be clearly understood that sufficient work has not been completed to permit unrestrained extrapolation of the conclusions outlined below. Of equal importance, however, is the fact that the type of analysis illustrated here can be and, it is hoped, will be enlisted by other workers in the field and extended to other situations.

Of major importance is the fact that the filtration process does not occur uniformly over the length of a filter bag. Different quantities of dust are collected at various altitudes within the bags, filter velocities can vary widely from one position to another, and the properties of the filter medium, that is, the resistance and the permeability, can fluctuate tremendously as a function of bag length. In Figure 3, for example, are shown dust mass profiles measured at various times through the progress of a single filtration period. Consider first the  $w_{0,1}$  profile produced by the preceding one-minute shaking period. While the average residual dust mass was 143 grains/ft<sup>2</sup>, the local residual dust mass ranged from 40 to as high as 194 grains/ft<sup>2</sup>, almost a 5:1 variation. Referring to the corresponding resistance profile,  $s_{0,1}$  in Figure 4, it should be noted that this profile has even higher percentage variations from position to position than the dust mass profile,  $w_{0,1}$ . A 10:1 resistance range over the bag length is seen. These variations with length are explainable on the basis of (a) differences in ease of removal of dust cake and/or differences in cleaning intensity along the

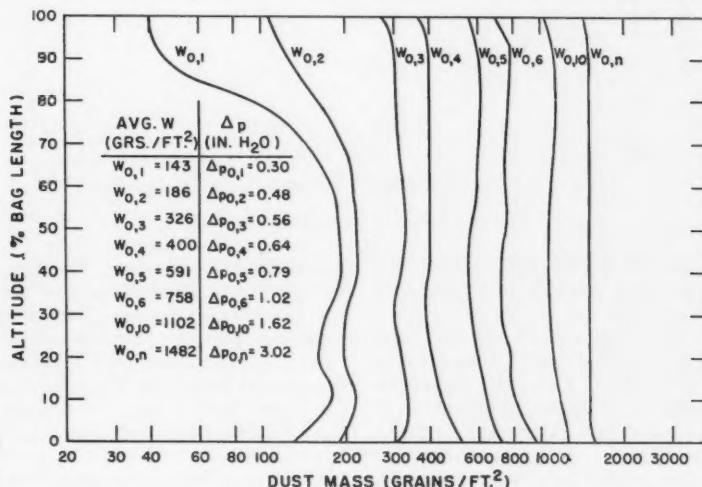


FIGURE 3. Development of dust mass profile through a filtration period.

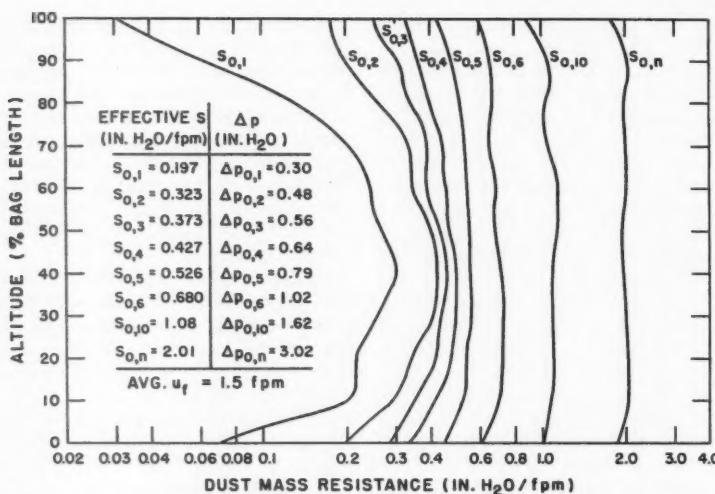


FIGURE 4. Development of dust mass resistance profile through a filtration period.

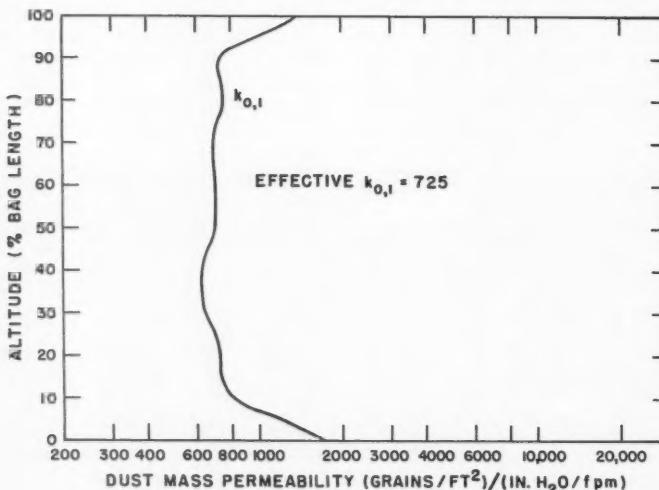


FIGURE 5. Residual permeability profile.

length of the bag, and (b) differences in structure (permeability) of the residual dust mass as a function of length. The points under (a) above are rather easily visualized, but the structural differences are more readily seen in the permeability profile of Figure 5. From this curve, the higher permeabilities in the upper and lower 10 percent of the bag length are immediately evident.

The successive profiles from left to right in Figures 3 and 4 were measured at the filter pres-

sure differentials indicated. The general tendency towards flattening of the profiles is observed, as well as is the development of characteristic deviations from linearity near top and bottom of the bags. The gross trend toward linearity is only to be expected since areas of low resistance will handle higher than average air volumes and vice versa. Consequently more dust is deposited on the low resistance areas, less on the areas of high resistance, and a self-balancing system exists. This tendency towards linearity was observed in every

filtration period conducted here and the disappearance of the  $w_{0,1}$  and  $s_{0,1}$  profile shapes occurred quite consistently during the interval in which between two and three times the residual dust mass was being filtered. The variations in profile slopes near top and bottom of the filters also appeared with high consistency throughout all experimental runs, and careful tests were conducted to prove that their appearance was not due to instrumental errors which might be inherent near the ends of the bags. Results of these tests confirmed the existence of the terminal variations and offered proof that even when starting with a perfectly flat profile, dissimilarities will evolve along bag length, especially near the top and bottom of the bags. A possible explanation of this phenomenon lies in elutriation. That is, from a theoretical standpoint at least, particle size segregation due to elutriation will occur from one end of a filter bag to the other.

Of even greater significance than the permeability variations with bag length are the changes in effective dust mass permeabilities observed through every filtration period. Permeabilities were found to increase, decrease, or to remain essentially constant in various specific situations, but in the majority of cases, permeability was found to decrease as filtration progressed. An excellent example of this is illustrated in Figure 6. In this case the  $k_{0,n}$  profile, having an effective value of 2940 (grains/ft<sup>2</sup>)/(inch H<sub>2</sub>O/fpm), was measured just after the bags had been shaken ( $\Delta p = 0.07$  inch H<sub>2</sub>O). By the time  $\Delta p$  had reached one inch H<sub>2</sub>O the effective permeabil-

ity had decreased to 991; at 2 inches H<sub>2</sub>O it was down to 671, and at 3 inches H<sub>2</sub>O, just before shaking, it had been reduced to 553 (grains/ft<sup>2</sup>)/(inch H<sub>2</sub>O/fpm). This type of data points up dramatically that the often-quoted "specific resistances" or "filter resistance coefficients" assigned to various dusts are not necessarily constant for that material but that their values may also be dependent upon the length of the filtration period.

Reasons for such changes in permeability as are shown in Figure 6 can be hypothesized. For example, it would be expected that permeabilities just after shaking should be relatively high since the cake has just been violently disturbed and a number of fissures and pinholes undoubtedly have been created. When filtration begins, these fissures are rapidly repaired, causing a very rapid decrease in permeability. The effect of these discontinuities on permeability may extend through the initial part of the filtration period, but by the time the  $k_{0,2}$  profile had been created (an average of over 1000 grains/ft<sup>2</sup> had been collected), these effects would surely have vanished. It seems inconceivable that this situation could cause decreasing permeability through the entire filtration period (in this case up to  $\Delta p = 3$  inches H<sub>2</sub>O and an average dust mass of 2280 grains/ft<sup>2</sup>).

From the theoretical definitions applicable to permeability [see equations (1) to (4)], it is seen that changes in permeability will result from changes in void volume, particle size, or particle packing characteristics (for a given dust, shape and surface properties are presumed constant).

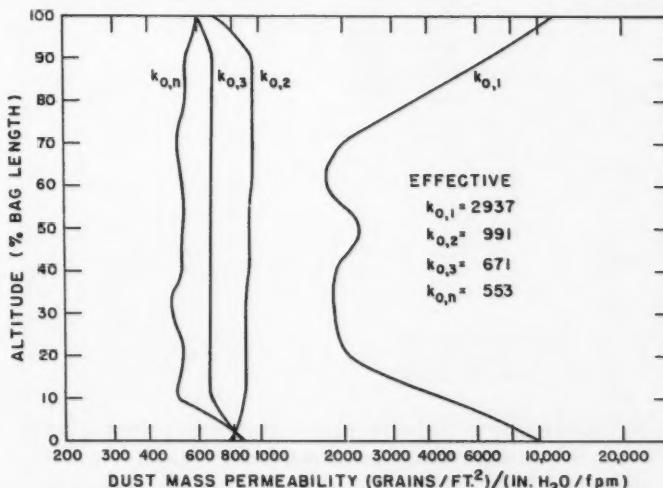


FIGURE 6. Decrease in dust mass permeability through a filtration period.

Decreases could occur in two ways; first, the dust cake could be formed in an increasingly more compact manner, or second, the structure of the existing dust cake could be changed. Since, as far as is known, the characteristics of the inlet dust stream remained constant during any filtration period, no logical reasons can be advanced to support the former hypothesis, but the latter is felt to be reasonable. The existence of gross structural shifting, cake collapse, has been verified experimentally as will be subsequently shown. Also, by the very mechanisms of aerosol collection on fabric air filters, particles are deposited within the existing cake, and since some particles pass completely through the filter medium (collection efficiencies are less than 100 per cent), it can be stated that deposition occurs throughout the entire cake thickness. This deposition must result in decreases in existing cake permeability; the magnitude of these changes will depend upon the specific conditions involved.

As indicated above, changes in permeability were not limited to decreases with time. Figure 7, for instance, shows changes in local permeabilities through the progress of the filtration period represented in Figures 3 and 4. Permeabilities at 5%, 50%, and 95% altitudes are represented. One ob-

serves that the first layer of dust (between 0.36 and 0.54 inch  $H_2O$ ) caused a sharp decrease in permeability. This layer presumably closed the perforations which had been created by the shaking action. As  $\Delta P$  increased to about one inch  $H_2O$  the permeability rapidly increased as if approaching that of a dust cake uninfluenced by fabric structure, i.e., the fraction of the total resistance attributable to the residual dust coat and to the very first dust deposited becomes smaller and smaller. From  $\Delta P = 1.0$  to 1.9 inches  $H_2O$ , permeability apparently fluctuated but with a generally slight downward trend, possibly due to penetration of fines into the matrix. From 1.9 to 3.1 inches  $H_2O$ , permeability dropped by more than 30 per cent to about 750 (grains/ $ft^2$ )/(inch  $H_2O$ /fpm), and this is believed to be the result of matrix collapse. It is very interesting to note that simultaneously, on the same filter bag, permeability can increase at one level and decrease at another as illustrated during intervals A, B, and C of Figure 7. It should also be noted that the effective permeability at the start of this filtration period was 725 and that at the end was 736. Hence, if one had simply calculated effective permeability at the beginning and end of this filtration period, he would probably conclude that

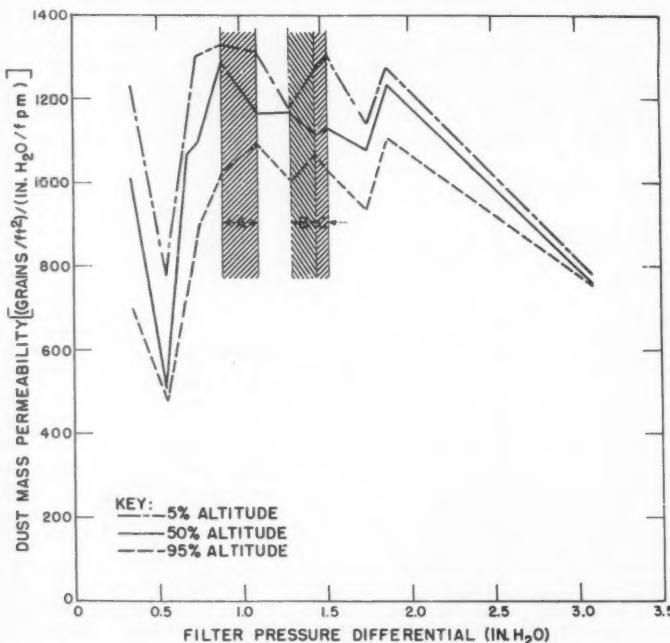


FIGURE 7. Variations in local dust mass permeabilities through a filtration period.

permeability had remained constant during the entire period, varying less than two per cent from the average value.

Cake collapse has been observed experimentally on both bench-scale apparatus and the pilot-scale baghouse. In experiments with fly ash on the bench-scale equipment, cake collapse can be quite routinely triggered by gradually increasing air flow through a dust cake supported on a flat, circular filter 1.5 inches in diameter. It appears that deformation of the matrix occurs in steps over appreciable intervals of filter velocity. As positive proof of the collapse phenomenon, actual cake thicknesses were measured with a microscope having a graduated micrometer fine adjustment and irreversible cake compressions of as much as 50 per cent of the original cake thickness were observed.

In an experiment with the pilot-scale baghouse, the filters were loaded to an average dust mass of 950 grains/ft<sup>2</sup> at an average filter velocity of 3.4 fpm. The resultant pressure differential was 3.4 inches H<sub>2</sub>O and, hence, effective permeability is seen to be 950 (grains/ft<sup>2</sup>)/(inch H<sub>2</sub>O/fpm). Filter velocity was lowered to about 0.75 fpm and then raised to 5.9 fpm during which time permeability remained constant at 950 (see Figure 8). As filter velocity was gradually increased above 5.9 fpm, however, permeability decreased rapidly to 785 at  $u_f = 6.5$  fpm. From 6.5 to 7.2 fpm the permeability of 785 was maintained. Between 7.2 and 7.6 fpm a second collapse occurred, further reducing permeability to 745, a value which was maintained up to 8.1 fpm. At this

point, filter velocity was reduced to 5 fpm to substantiate that a new matrix structure of lower permeability had been created. Two more distinct collapses were observed as filter velocity was ultimately raised to 9.8 fpm, and, after each of these, filter velocity was lowered and then raised, authenticating a new, more compact cake structure in each instance. After the final collapse, permeability had been reduced to 585, or to roughly 60 per cent of the permeability of the uncollapsed cake. Since, in this case, dust mass remained constant during the entire test, permeability and resistance are inversely proportional to one another. In these terms, effective resistance was increased from 1.0 inch H<sub>2</sub>O/fpm for the uncollapsed cake to 1.62 for the final collapsed cake. Hence, filter resistance was increased by more than 60 per cent as the result of the collapse.

Cake puncture has also been confirmed experimentally. On the bench-scale flat filter it could not be induced even at very high pressure differentials when a cake support of low porosity (glass filter paper, membrane filters, etc.) was employed. However, when a filter fabric such as the cotton sateen used in the filter bags was used as the support, puncture occurred as shown in Figure 9. It is seen that the unpunctured cake had a resistance of 1.0 inch H<sub>2</sub>O/fpm. As filter velocity was raised over 10 fpm, resistance began to decrease sharply and continued to decrease, approaching about 0.47 asymptotically. This type of resistance decrease is what would be expected, since a limit to the degree of reduction of filter

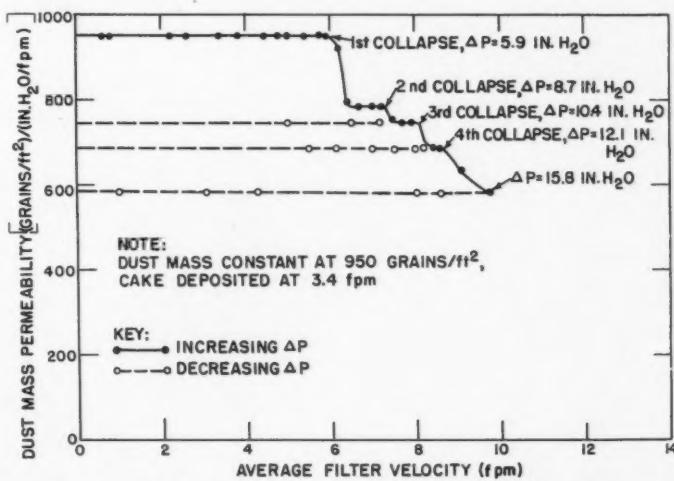


FIGURE 8. Successive cake collapses observed on pilot-scale baghouse.

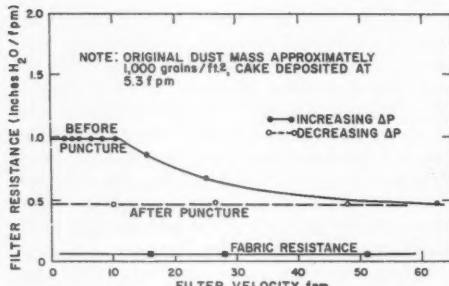


FIGURE 9. Cake puncture observed on bench-scale filter.

resistance by this mechanism must obviously exist. Reduction of filter velocity back to 10 fpm verified the constant resistance of the punctured cake. In cases such as this, the pinhole punctures created were easily visible on microscopic examination of the cake against a bright light.

One extreme example of cake puncture occurred during operation of the pilot-scale baghouse. During an interval in which there was no

air flow to the filters, a small piece of the existing dust cake fell from one of the bags. This, of course, reduced the resistance tremendously at this one spot and, as a result, filter velocity was extremely high through this area when flow was started. By application of the effective filter resistance equation presented earlier [equation (12)], it may be calculated that the filter velocity through the area of the puncture must have been on the order of 100 fpm when air flow was first started! This is a fantastic value when one realizes that the average filter velocity at this time was only 0.75 fpm. Of further significance is the fact that even at the high velocity through the puncture, the self-repairing mechanism described earlier took place. A filter velocity profile was measured after some eight minutes of filtration. At this time the filter velocity through the puncture had dropped to 2.3 fpm and the area of the puncture appeared as shown in Figure 10.

The resistance and permeability concepts can also be of value to filter cleaning evaluation. For example, Figure 11 shows a mass profile just before cleaning, the mass remaining after a one-minute cleaning period, and the mass left after 20

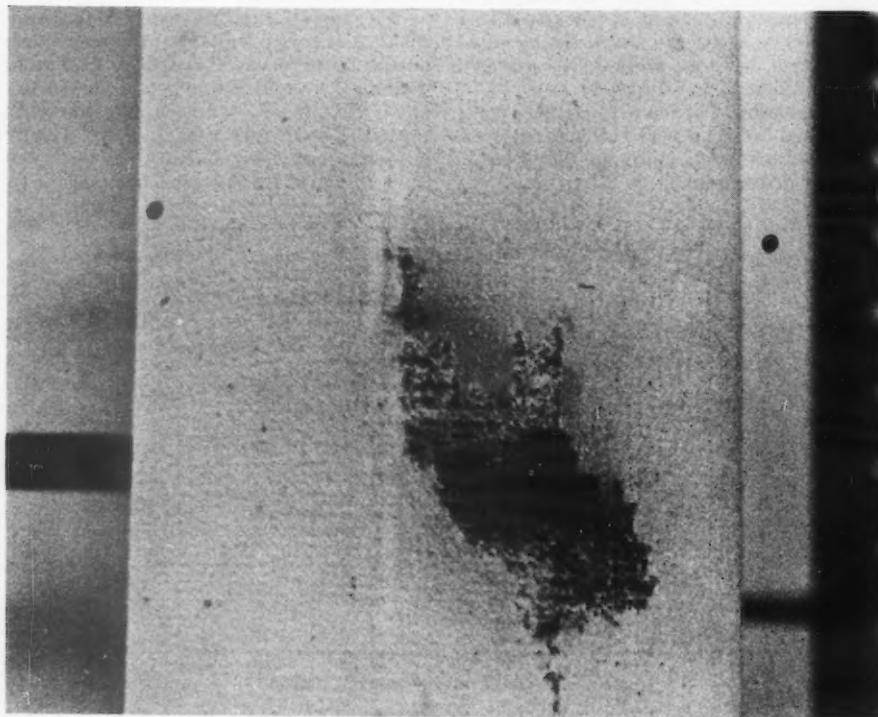


FIGURE 10. Appearance of local cake puncture on pilot-scale baghouse.

minutes of shaking. One sees that in this particular case, 89.5 per cent of the dust cake was removed by one minute of shaking and 97.2 per cent by a 20-minute cleaning period. The reductions in resistance produced by the same shaking periods are illustrated in Figure 12. The first one minute of shaking reduced resistance by 89.7 per cent and the next 19 minutes reduced it by only an additional 2.8 per cent. One significant point here is that, from a practical view, dust removal itself is of little real importance in evaluating a given type of shaking action and that, rather, the resistance decrease is what will determine the pressure drop after shaking. Secondly, before shaking, the cake had an effective permeability of 949 (grains/ft<sup>2</sup>)/(inch H<sub>2</sub>O/fpm) and this value was slightly increased to 970 by one minute of shaking. But, after 20 minutes of shaking, permeability was reduced to 356. While this may seem unreasonable on first inspection, it simply accentuates the fact that in some cases, such as this, continued shaking may reduce dust mass proportionally more than resistance. This result reconfirms that reduction in effective resistance is more meaningful than quantity of dust removed in determining optimum lengths of cleaning periods.

#### Practical Implications

A number of implications of a practical nature are present in the research results obtained to date. In the first place, the very ability to study and to describe filtration as a function of location on the filter surface provides a heretofore un-

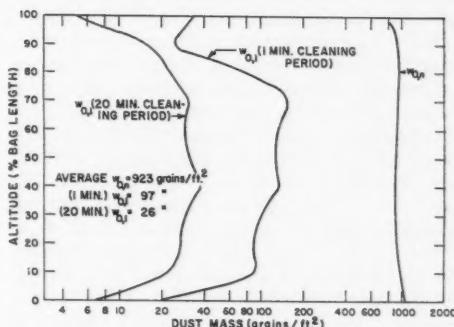


FIGURE 11. Effect of cleaning period on residual dust mass profile.

available insight into the filtration process. For example, it has generally been tacitly assumed that actual filter velocities were equal to the overall average filter ratio of an operating baghouse. In reality, it is now seen that true filter velocities can differ widely from the average value and that velocities through a given incremental filter area can change considerably through a filtration period. As a corollary to this, it is recognized that the filter cake is deposited, not at a uniform velocity, but at a continuously varying velocity generally approaching the average filter velocity with time. This recognition, in turn, can lead to more realistic representation of filter cakes in laboratory equipment.

The hints at elutriation of particulates within filter bags are certainly of practical significance.

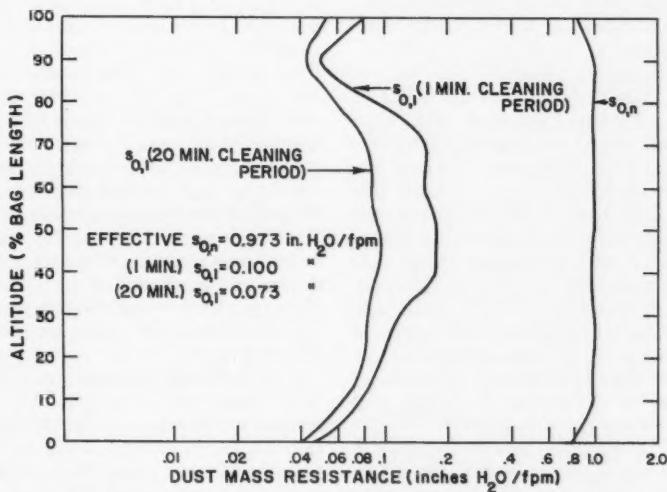


FIGURE 12. Effect of cleaning period on residual resistance profile.

The fact that a different size distribution may be filtered at each altitude within a bag offers another refinement technique to the laboratory investigator attempting to duplicate commercial-scale operation in miniature equipment. The importance of the elutriation phenomenon in a particular case will be influenced by the particle-size distribution of the dust being collected. This may mean that particle sizing techniques, especially those evaluating particle size as it actually exists in the air stream, deserve increased attention as tools in air filter design. It is possible that consideration of elutriation within tubular filters, or the lack of it, could lead to important conclusions regarding the optimum length-to-diameter ratios for filter bags.

A possible relationship between local permeability or resistance and local collection efficiency is not unlikely. Should this be true, it could be inferred from profiles such as  $s_0$ , in Figure 4 that (a) if collection efficiency is low just after cleaning, the areas of low efficiency will be known and changes in shaking conditions can be invoked to correct this; or, (b) if collection efficiency is high just after cleaning, the particular dust-fabric combination involved should yield satisfactory collection efficiencies at filter velocities on the order of those through the low resistance areas.

The measurement of mass and resistance profiles in studies of filter cleaning should aid immensely in the evaluation and comparison of various cleaning mechanisms. Proper choice of experiments can give information as to both cleaning intensity and ease of cake removal over the entire filter surface. Profiles measured on reverse-jet filters can provide information regarding the optimum jet velocity-ring travel speed combination.

The fact that a given permeability is not necessarily characteristic of a given dust points up the need for improved evaluation techniques. This type of variation in dust cake characteristics was suggested in 1955 by Snyder and Pring<sup>6</sup> and the current research has led to emphatic substantiation of their work. It also leads to serious doubt as to the utility of the simplified laboratory tests so often used in baghouse design. The existence of variations in cake permeability suggests research on the relationship of permeability to matrix structure. Control over cake permeabilities, for example through the utilization of agglomerating techniques, fractional recycling, or conceivably through the seeding of the inlet dust stream with a foreign particulate contributing to the formation of a highly permeable dust cake, is a possible outcome of such research. Since permeability is dependent upon the square of the

effective particle diameter within the cake, the presence of a greater fraction of large particles should enhance high permeabilities; from this implication one might conclude that, as has been suggested,<sup>7</sup> the use of precleaners, even the conventional baghouse hopper itself, may be unwise.

Cognizance of the cake collapse phenomenon can help in avoiding both underdesign and overdesign of commercial units. As an example, if the dust to be filtered behaved in the manner illustrated in Figure 8, appreciable underdesign could occur if laboratory tests were performed on a cake having the uncollapsed permeability, 950 (grains/ft<sup>2</sup>)/(inch H<sub>2</sub>O/fpm), while commercial operation produced a permeability at, say, the first collapse level, 785. On the other hand, if tests such as those described by Williams, Hatch, and Greenburg<sup>8</sup> were employed (cake deposition velocity in the laboratory test unit held constant at 10 fpm), the baghouse would be designed roughly 25 per cent oversize if it were to be operated at, say, 3 fpm. Such a consideration could certainly make or break many installations. Also, in selecting air handling equipment, fan characteristics should be checked to ascertain that the higher volumetric flow rates, obtained while filter pressure differential is low, do not result in filter velocities causing collapse during the initial stages of a filtration period.

Of a more basic nature, research on the collapse phenomenon itself should be profitable. Knowledge of its mechanism and the factors affecting it might lead to techniques for avoiding cake collapse altogether.

In areas where extremely high efficiencies are imperative, incidents such as that shown in Figure 10 must be avoided. Hence, air flow should never be shut down without cleaning the entire filter surface; and, if the filter is cleaned, it must be cleaned relatively uniformly over its whole area. This puncture episode also demonstrates another basic point. Pressure differential can be reduced greatly by lowering the resistance of a relatively small fraction of the total filter area; but, when filtration is restarted, the pressure differential increases very rapidly, perhaps almost instantaneously, back to its previous value. This illustrates well that effective cleaning is uniform cleaning, and that reduction in pressure differential is not necessarily a good criterion for cleaning effectiveness.

Most intriguing, perhaps, are changes in established design or operating practices which may be imagined. One may conceive of an inertial separator, a simple cyclone, which could be used to separate the coarse and fine fractions of the dust stream to be controlled. By a suitable program-

ming mechanism, the coarse fraction could be fed to the just-cleaned sections of a multi-compartmented baghouse to produce the initial dust layer over the residual dust coat. After this layer had been deposited, the fine fraction could be introduced to these compartments for the remainder of the filtration period. Such a procedure could conceivably allow operation at higher average filter velocities since the fabric would be "protected" in large part, from impregnation by fine particles, resulting in increased over-all permeabilities.

It must be emphasized, in closing, that the data interpreted in the preceding paragraphs were obtained under particular, restricted operating conditions and with one type of dust and one type of filter fabric. Certainly, it is highly probable that similar phenomena will be observed under other specific test conditions. It is felt that further work employing local dust mass and filter velocity determinations and utilizing the concepts presented above can yield a high return in practical design and operating criteria, or, hopefully, generalized correlations.

### Nomenclature

$A_f$	= available filter area, $\text{ft}^2$
$A_p$	= surface area of particle, $\text{ft}^2$
$a_1, a_2, a_3, \dots a_n$	= incremental filter areas, $\text{ft}^2$
$C_K$	= coefficient in Kozeny equation, $\text{ft}/\text{min}^2$
$D_c$	= characteristic diameter of flow channel as used in the Hatch equation, feet
$D_{pe}$	= effective diameter of particles, feet
$E$	= electrical driving force, volts
$F_a$	= fractional effective free cross-sectional area of granular medium, dimensionless
$g_c$	= conversion factor, $\text{ft lb mass}/\text{min}^2 \text{ lb force}$ = $115,800 \text{ ft lb mass}/\text{min}^2 \text{ lb force}$
$g_L$	= local acceleration of gravity, $\text{ft}/\text{min}^2$ = $115,800 \text{ ft}/\text{min}^2$
$I$	= electrical current, amperes
$J$	= conversion factor, $(\text{inches H}_2\text{O})/(\text{lb force}/\text{ft}^2)$ = $5.21 (\text{inches H}_2\text{O})/(\text{lb force}/\text{ft}^2)$
$K$	= permeability of filter medium, $(\text{grains}/\text{ft}^2)/(\text{inch H}_2\text{O}/\text{fpm})$ = $W/S$
$K_D$	= proportionality factor in D'Arcy's equation, $(\text{ft}^2)/(\text{inch H}_2\text{O})(\text{min})$ = $L u_f / \Delta P$
$K_{F\&H}$	= coefficient in Fair & Hatch equation, dimensionless
$K_H$	= coefficient in Hatch equation, dimensionless

$k$	= permeability of dust mass, $(\text{grains}/\text{ft}^2)/(\text{inch H}_2\text{O}/\text{fpm})$
$w/s$	= $w/s$
$L$	= thickness of filter medium, feet
$\Delta P$	= filter pressure differential, inches $\text{H}_2\text{O}$
$\Delta p$	= portion of filter pressure differential attributable to dust mass, in. $\text{H}_2\text{O}$
$\Delta P_0$	= $\Delta P - \Delta P_0$
$Q$	= volumetric flow rate, $\text{ft}^3/\text{min}$
$R_e$	= effective resistance of electric circuit, ohms
$R_1, R_2, R_3, \dots R_n$	= respective individual resistances in electric circuit, ohms
$S$	= local filter resistance (referred to one $\text{ft}^2$ of filter area), inches $\text{H}_2\text{O}/\text{fpm}$
$S_{a_1}, S_{a_2}, S_{a_3}, \dots S_{a_n}$	= average filter resistance (referred to one $\text{ft}^2$ of filter area) over area, $a_1, a_2, a_3, \dots$ , etc., inches $\text{H}_2\text{O}/\text{fpm}$
$S_e$	= effective filter resistance (referred to one $\text{ft}^2$ of filter area) over available filter area, inches $\text{H}_2\text{O}/\text{fpm}$
$S_e'$	= effective filter resistance over available filter area, in. $\text{H}_2\text{O}/\text{fpm ft}^2$
$s$	= local dust mass resistance (referred to one $\text{ft}^2$ of filter area), inches $\text{H}_2\text{O}/\text{fpm}$
$u_f$	= local filter velocity, $\text{ft}/\text{min}$
$u_{f,avg}$	= average filter velocity, $\text{ft}/\text{min}$
$V_p$	= volume of particle, $\text{ft}^3$
$W$	= areal density of filter medium, $\text{grains}/\text{ft}^2$
$w$	= local areal density of dust mass, $\text{grains}/\text{ft}^2$
$\alpha$	= void fraction, dimensionless
$\mu$	= fluid viscosity, $\text{lb mass}/\text{ft min}$
$\rho_b$	= bulk density of filter medium, $\text{grains}/\text{ft}^3$
<i>Subscripts:</i> Single subscripts refer to the following:	
0	refers to properties of the filter fabric itself.
1	refers to properties of the filter medium just after cleaning.
2, 3, 4, etc.	refer to properties of the filter medium at the times of the second, third, fourth, etc. profiles of a filtration period.
$n$	refers to properties of the filter medium just before cleaning.

Double subscripts refer to the properties of the dust mass deposited during the interval indicated; for example,  $s_{0,1}$  is the resistance of the dust mass remaining after cleaning, i.e.,  $s_{0,1} = S_1 - S_0$  and  $s_{3,4}$  is the resistance of the layer of dust deposited between profiles 3 and 4, i.e.,  $s_{3,4} = S_4 - S_3$ .

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#### POSTGRADUATE COURSE

THE UNIVERSITY OF WISCONSIN will present a course on "Effects of Air Pollution and Environment on Health" at the Wisconsin Center Building, Madison, May 19-20, 1960. Dr. Seymour B. Crepea, Associate Professor of Medicine and Director of the Allergy Clinic at University Hospitals, is the course Director. The staff from the University of Wisconsin will be augmented by speakers from several other medical schools and the U. S. Public Health Service. The course will be a clinical discussion on various phases of air pollution, and their effect on health. Industrial pollution, air-borne infections, and problems of rural air pollution will be considered. Physicians, engineers, and faculty members of colleges of agriculture and medicine will be interested in this course.

Requests for information and registration should be sent to Dr. Robert C. Parkin, Coordinator of Graduate Medical Education, University of Wisconsin Medical School, 418 North Randall Avenue, Madison 6, Wisconsin.

#### AIR POLLUTION RESEARCH PROJECTS

THE AMERICAN SOCIETY of Mechanical Engineers has established a Task Group on Research in Air Pollution to undertake the compilation of a listing of active research projects in this field. The inventory will consist of research projects which were active during 1959 and will include the identity of organizations and research workers associated with the various projects. The Task Group sent out questionnaires during December to begin gathering the data. If you did not receive such announcement and questionnaire and you have projects which should be included, please communicate with Mr. Austin Heller, Chairman, Task Group on Air Pollution Research, American Society of Mechanical Engineers, 29 West Thirty-ninth Street, New York 18, New York. Requests for copies of the completed inventory should be directed to Mr. Heller also.

# Determination of Pentaborane in Air by Means of Activated Carbon\*

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THE DETERMINATION of pentaborane in air has been a vexing and most difficult problem which became particularly pressing during animal tests carried out to determine its toxicity when administered by inhalation, which would be the case in most accidental industrial exposures. Because similar exposure tests with decaborane had been made on previous occasions, methods that had been developed for its detection and quantitative determination were first employed also for pentaborane. However, results obtained with one of these methods (absorption in aqueous alkali) were considerably lower than calculated values, at exposure levels of some 50-80 ppm of pentaborane, and they became valueless at levels of several parts per million or less. Quinoline, which proved such a good reagent for decaborane,<sup>1</sup> gave only a fleeting pink color with pentaborane and thus could not be employed for its quantitative determination. Absorption in trains of Vigreux bubblers containing either acidified water, or acidified methanol, or even concentrated sulfuric acid, gave only partial and very erratic recovery of the calculated amounts of pentaborane and had to be abandoned. Moreover, it was found that fritted glass gas-dispersion tubes used in some experiments contributed substantial amounts of boron, particularly when they were fairly new. Iodometric titration in a Tutwiler burette<sup>2</sup> was found feasible at higher concentrations but was very slow and the endpoints were somewhat uncertain. Use of standard iodine solutions in Vigreux bubblers (followed by thiosulfate to catch iodine vapors) and back titration with thiosulfate was not found profitable under the conditions which we tried.

It appears thus that pentaborane behaves quite differently than do diborane or decaborane; it does not dissolve readily in alkali, it does not hydrolyze very readily in liquid media, and it generally behaves much more like a hy-

drocarbon, i.e., it does not seem to be wetted readily by aqueous solutions.

In an effort to borrow from the manufactured gas industry, attempts were made to scrub the air containing pentaborane with high boiling oils, such as decaline and tetriline. While retention seemed fairly good, as judged by failure to detect the borane in the exit air by the reagents known to us, all attempts to recover boron from such solutions by hydrolysis and methyl borate distillation led to unsatisfactory results, largely because some of the high boiling oils were always carried over and caused browning of the concentrated sulfuric acid used in the Carmine determination of boron.<sup>3</sup>

The only really promising lead to a method employing a liquid reagent was encountered when triphenyltetrazolium chloride, a compound which had been found on another occasion to give color with pentaborane as well as with decaborane, was employed.<sup>4</sup> Results were in the right direction, but the preparation of standardization curves met with great difficulties at that time and, because of the pressing needs for an immediately useful procedure, work on this method was temporarily shelved. In the meantime it has been taken up again and a separate paper on this subject will be published in the near future.

Further consideration of the problems of the manufactured gas industry, and general physico-chemical considerations, finally led to a satisfactory method. It is well known that in recovering light oil from manufactured gas a substantial quantity always escapes absorption in spite of the fact that scrubbing with heavy oils is accomplished in a counter current procedure in which fresh wash oil contacts the already largely debenzolized gas. No such procedure can be employed conveniently in the laboratory, and it certainly was not employed by us when a number of Vigreux bubblers were arranged in series for the absorption of pentaborane from the air of the inhalation chambers. Removal of the volatile components by freezing in a cold trap also

\* The work reported in this paper was sponsored by the Callery Chemical Company under a contract from the Bureau of Aeronautics, Department of the Navy.

does not lead to complete recovery. The reason for these failures lies in the fact that scrubbing liquids (as well as solid or liquid frozen out) will always have a certain vapor tension with respect to the volatile component to be removed, unless reaction with the scrubbing liquid has taken place, so that complete removal cannot be hoped for. This becomes the more pronounced the lower the concentration of the vapor in the air. Berl, Andress and Müller<sup>6</sup> have shown that even at concentrations of hundreds of parts per million of benzene and its homologues not more than about one half of the volatile component is removed from manufactured gas by laboratory oil scrubbing or freezing out. For this reason they devised the method of adsorption on activated carbon which has become an accepted method in industrial hygiene practice for the determination of organic vapors in air or gas, and which removes the vapors substantially completely. Berl and Andress<sup>6</sup> found that no substantial bleeding through of benzene occurs if the benzene load on the carbon is less than 15% by weight, and that with two tubes of activated carbon in series, a maximum load of benzene on the carbon of 31% can be reached without benzene appearing in the exit gas. Moreover, we had observed in our work on gas mask protection against the boranes<sup>7, 8</sup> that activated carbon was a particularly good agent for the retention of pentaborane. It was decided, therefore, to apply these considerations to the determination of pentaborane in the air of our animal inhalation chambers.

The apparatus chosen was very simple and rugged with a view to plant requirements of lightness, compactness, sturdiness and low cost. Bearing in mind that all boranes are absorbed readily by rubber, with subsequent further vulcanization and embrittlement of the latter, ball and socket joints were employed exclusively. If connections other than glass become necessary in plant operation, they should be made of Tygon tubing but not of rubber. The collection equipment consists of a glass tube of about 10 mm inside diameter, with ball and socket joints fitted to the respective ends, and a fritted glass plate fused into the tube about 2 inches from the ball end. About 5 grams of activated carbon (Mine Safety Appliances Company's "60 Minute" grade) are put into the tube and the latter is tapped gently to settle the carbon in place. When used for chamber analysis, the tube is used in an upright position, the air entering the top and leaving the bottom. In this manner the carbon bed remains undisturbed throughout the test period and channeling is minimized.

The kind of carbon used is of considerable

importance because we have found that the boron content of activated carbon may vary quite considerably. The materials supplied by Mine Safety Appliances Company have generally run from 13 to 32 micrograms of boron per 5 grams of carbon, but other commercial carbons have as much as 180 micrograms of boron for the same size batch. In our work we have customarily subjected a "blank" lot of carbon to the same treatment as is used for the carbon in an actual pentaborane determination and have used the resulting boron containing distillate as a blank against which final spectrophotometric readings were made. It is, of course, also possible to determine the boron content of the carbon in a separate series of determinations and to then deduct the mean figure from the results obtained in actual pentaborane determinations. A mesh size of 8-14 has been found useful, but coarser or finer material may be employed if desirable for the one or the other reason. This will depend on the total amount of air put through the carbon, the diameter and length of the collecting tube, the velocity of the air current, and the concentration of pentaborane in the air to be sampled.

In taking samples for analysis, the air (or gas) is passed through the carbon at room temperature at a rate of from 0.2 to one or even several liters per minute, depending on the pentaborane concentration. We have customarily used 0.5 liter per minute at concentrations of up to about 15 ppm. Berl, Andress and Müller<sup>6</sup> have used velocities of from 70 to 235 liters per hour for their benzene work, but they used a larger amount of carbon (30-40 grams) and a collecting U-tube of larger dimensions. It would, therefore, seem entirely appropriate to use greater velocities in pentaborane analysis if so desired and if the amount of carbon and the dimension of the collecting tube were modified accordingly. Where greatest accuracy is wanted, two tubes should be used in series. The total air sample in our work has been about 50-150 liters for pentaborane concentrations of 0.2 ppm, and 1-3 liters will suffice at concentrations of about 15 ppm. This is not critical and will depend on the method of boric acid analysis employed in the final step. Direct titration in the presence of mannitol will obviously require a much larger amount of boric acid, and therefore, a larger air sample, than microanalysis by the Carmine method of Hatcher and Wilcox,<sup>9</sup> or others. After the sample has been taken, the tubes are closed with ball and socket plugs so that losses cannot occur. In this way many samples can be taken in the plant and can be analyzed in the laboratory when convenient. Temperature is not of

great importance for the collection. We tried keeping the carbon at low temperatures ( $-10^{\circ}\text{C}$ ) by surrounding the collecting tube with a mantle through which dry ice cooled Prestone was circulated and by precooling the incoming air by the same means, but no beneficial results were obtained. This is in line with findings by Berl and Andress<sup>8</sup> that the temperature coefficient is small for activated carbon, so that only 1.2 times as much is adsorbed at  $0^{\circ}\text{C}$  as is adsorbed at  $20^{\circ}\text{C}$ . This slightly increased adsorption capacity does not warrant the complications introduced by the provisions for cooling, which would be particularly disadvantageous in plant practice.

Determination of the boron adsorbed by the carbon proved more difficult than was first visualized. While "stewing" of the carbon sample with 50% caustic soda on a steam bath and subsequent methyl borate distillation has given fair results, it is somewhat erratic, probably because the carbon is poorly wetted by the caustic solution. Much more consistent results are obtained if the carbon is transferred from the sample tube to a 100-ml round bottom Pyrex flask, then subjected to a toluene azeotropic distillation to remove water adsorbed by the carbon during the sampling, followed by a methyl borate distillation in the same apparatus. The setup used for the purpose is the same as described by Hill, *et al.*<sup>9</sup> in a paper entitled "Analysis of Biological Materials for Boron". The distillate obtained is then further analyzed for boric acid by the Carmine method of Hatcher and Wilcox.<sup>2</sup>

While it might appear attractive to simplify the whole procedure by weighing the carbon tube before and after sampling, this is not permissible in fact even if the moisture of the air were removed before the air enters the carbon tube. There is good evidence for the belief that the pentaborane is catalytically oxidized and/or hydrolyzed on the carbon but it is not known whether it is converted merely to boron oxide or to boric acid or to a mixture thereof. Thus, an attempted determination of pentaborane by weight gain (*e.g.*, at higher concentrations) would be entirely illusory. We came to this postulate of catalytic oxidation (or hydrolysis) through the observation that no borane could be proven on the carbon from sample tubes by any of the methods known to us, to wit, treatment with triphenyltetrazolium chloride reagent, treatment with amylose-silver nitrate reagent,<sup>10</sup> and the phosphomolybdate reaction.<sup>11</sup> Because of the inherent tediousness of the methyl borate distillation for the recovery of boron from the carbon sample, at-

tempts were also made to simply burn the carbon in the Parr Oxygen Bomb.<sup>12</sup> However, the boron was always found to be much too low. No explanation can be offered at this time as to the reasons for this failure, though it might be conjectured that boron carbide could have been formed. Work will continue on this subject and results will be published as they become available.

Results obtained with this method in monitoring animal exposure chambers and in gas mask development work,<sup>1</sup> have been quite satisfactory, though a casual look at the figures might indicate lack of precision or accuracy, or both. It is believed, however, that the results represent true values of prevailing concentrations and that insufficiencies of the method play a minor role. We had to rely on the nominal concentrations for which the toxicologist was aiming and which he calculated on the basis of air flows and the pentaborane concentrations of the pentaborane-nitrogen mixtures supplied to us for these investigations. The latter were not too reliable because we found one cylinder to be off 40 per cent from the figure given by the manufacturer. Moreover, the rotameters used for measuring the flow of the gases fluctuated quite a bit in spite of all efforts to steady them, and final dilution with air was accomplished by sucking additional air into the exposure chamber and depending for measurement on the calculation of the exhaust air volume by means of an orifice plate and pressure differential gauge. Also, it should not be forgotten that pentaborane hydrolyses and oxidizes like other boranes, and that it had plenty of chance to do so because of the large amounts of water vapor exhaled by the many animals in the chronic exposure chamber. Even the glass lines carrying the pentaborane (first dilution with air) into the chamber showed white films on the inside, unquestionably boron oxide or boric acid. The possibility of pentaborane being absorbed or adsorbed by the varnish coating of the wood walls of the exposure chamber and by the fur of the animals also cannot be ignored. Considering all the circumstances, it is believed that the analytical figures for the pentaborane levels of the chamber inlet air and for the chamber air proper, found by the activated carbon method, were reliable to better than 20 per cent and probably better than 10 per cent. Tables I and II present some of the results obtained on chamber monitoring and gas mask inlet and outlet tests. They illustrate the several points made above.

Table III shows that the efficiency of adsorption of pentaborane by activated carbon is excellent, at least if sufficient air is present. Two

TABLE I

Monitoring of Pentaborane Exposure Chamber by Activated Carbon Method

Air sample, liters	Boron found, micrograms	Pentaborane concentration, ppm		
		found	calculated	nominal
2.1	60	12.9		13.8
4.2	112.5	12.1		13.8
8.4	220	11.8		13.8
4.2	92.5	9.9		13.8
2.1	57.5	12.3		13.8
1.4	32	10.3		13.8
4.2	102.5	11.0		13.8
4.2*		13.7	13.8-13.9	
10†	67	3.4	5.6	8.0
10†	98	5.9	7.5	8.0
7.5	100	6.0	5.5	8.0
7.5	95	5.7	5.5	8.0
22.5‡	290	5.7		
7.5‡	100	6.0	5.5	8.0
7.5‡	110	6.6	5.5	8.0
27.5‡	90	1.5	3.6	3.0
10‡	45	2.0	3.3	3.0
12.5‡	42	1.5	3.3	3.0
12.5‡	38	1.4	3.3	3.0
15‡	130	3.9	3.3	3.0
15‡	110	3.3	3.3	3.0
15	112.5	3.4	3.3	3.0
15	112.5	3.4	3.3	3.0
10	75	3.4	10.7(?)	3.0
136	36.6	0.12		0.2
127.5	44.5	0.16		0.2
121.5	27.5	0.11		0.2
130.5	30.5	0.11		0.2
138	33.5	0.11		0.2
138	35.0	0.11		0.2
130	35.5	0.13		0.2
135	29.5	0.10		0.2
152.5	26.5	0.08		0.2
116.5	16.5	0.06		0.2
99	15.5	0.07		0.2
60	2.6	0.02		0.2

Notes: \* "Nominal" concentrations were those aimed for by the toxicologist;

† Calculated concentrations were obtained from the chamber flow rates.

At the lowest concentration level (0.2 ppm nominal) the inlet to the chamber (before final air dilution) ranged from 1.4-3.4 ppm as calculated from the flow rates.

\* Analysis of chamber inlet air during one of the gas mask tests.

† Azeotropic distillation of carbon with benzene before methyl borate distillation.

‡ Carbon treated with 50% aqueous NaOH before methyl borate distillation.

All other carbon samples were distilled with toluene before methyl borate distillation.

tubes were used in the tests in series, and the breakthrough is seen to be insignificant.

Application of the method to the analysis of the pentaborane-nitrogen mixture of the steel cylinders furnished by the manufacturer indi-

TABLE II

Analysis of Gas Mask Effluent for Pentaborane Content by the Activated Carbon Method

Sample #	Duration of gas mask test, cumulative hours	Sample size, liters	Boron found, micrograms	Pentaborane found, ppm
I*	0	4.2	157.5	16.87
II	6	43.9	1.5	0.02
III	12	67.5	0	0
VI	18	20.9	0	0
XI	24	13.5	3.4	0.11
XVI	30	13.7	3.4	0.11
XVII*		4.2	125.0	13.39
XVIII		13.5	7.6	0.25
XXIII	38	13.5	11.0	0.37
XXVI	40	27.0	24.4	0.41

Notes: \* These samples were taken from the stream entering the gas mask; the "nominal" concentration aimed for during the whole test was 13.6 ppm.

TABLE III

Analysis of Pentaborane Chamber Air by Two Activated Carbon Tubes in Series

Air sample, liters	Boron found, micrograms			Pentaborane conc., ppm	
	Tube 1	Tube 2	Total	found	nominal
4.2	182.5	0	182.5	16.7	14.6
8.4	370.0	1.6	371.6	17.0	14.6

Note: The "nominal" concentration was the one aimed for.

TABLE IV

Analysis of Cylinder Containing the Pentaborane-Nitrogen Mixture (67-77 grams carbon and 10 ml per minute sampling rate)

Gas sample, liters	Pentaborane found, micrograms	Pentaborane concentration, ppm	
		found	as per supplier
0.05	1063	8177	7259
0.10	1997	7682	7259
0.16	2765	6646	7259
0.30	4556	5841	7259

cated that in the absence of air, carbon is not too good an adsorbent for pentaborane because progressively lower concentrations were found as the amount of gas passed through the sample tube increased. This is seen from Table IV. It must be left unresolved whether our highest figure represented the true cylinder concentration, with the supplier's figure being off, or whether it is a chance result.

The method is, of course, not specific. There is every reason to believe that other boranes would be adsorbed by the carbon in like manner and since the carbon is analyzed for boron, there would be no means for differentiating several boranes. However, this is no shortcoming because methods for the analysis of diborane and decaborane are available and the present method would normally be used only when the air is definitely known to contain pentaborane, as was the case in our animal exposure tests. However, even if a work atmosphere containing several boranes were to be monitored by the carbon method, the results obtained would still be useful because the toxicity of the various boranes is of the same order of magnitude so that the errors involved would not be of critical importance.

While during this investigation it was not feasible to work out procedural details nor use precisely known gas concentrations because the pentaborane cylinders were needed for the animal exposure tests, we had occasion recently to get back to this work unencumbered by such considerations. Fluctuations of the rotameters continued to be bothersome, but at least we did not have to cope with animal fur, varnished walls, uncertain final air dilution volumes, etc. Results so far have been very gratifying with accuracies of about 10-15% being achieved at levels of about 0.2 ppm. Details of this new investigation will be published as soon as the work is completed.

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## DIGEST OF AIR POLLUTION LAWS

THE PUBLIC HEALTH SERVICE, U. S. Department of Health, Education, and Welfare has published "A Digest of State Air Pollution Laws." This digest was prepared by Samuel M. Rogers, Program Advisor, Air Pollution Engineering Program, and Sidney Edelman, Assistant Chief, Public Health Division, Office of the General Counsel. The pertinent laws of all fifty states, the District of Columbia, Puerto Rico, and the Virgin Islands have been reviewed in the preparation of this publication. This bulletin will be of real value and service to all persons concerned with air pollution control; it will undoubtedly save many weary hours of digging for information.

The digest is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. In ordering, specify Public Health Service Publication No. 711. (At our press time the price had not been indicated.)

# An Application of Gas Chromatography to Analysis of Solvent Vapors in Industrial Air

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A NUMBER of studies have been published describing the use of the gas chromatograph for atmospheric analysis. Among these is that of West<sup>5</sup> who presents a method using samples obtained by scrubbing the air through cooled, activated charcoal. The range of this method is from one to 50 parts per million. Another paper by Mansur, published recently,<sup>4</sup> describes a method in which methanol is used as a scrubbing medium. He has developed a number of nomographs based on the chromatograms to simplify conversion of peak heights to parts per million.

The following describes a simple, practical, and direct method of sampling air for chromatographic analysis of some industrial air contaminants.

## Apparatus

*Beckman GC-2 Gas Chromatograph* equipped with an 8.5 foot long Silicone 550 on crushed C-22 firebrick column. (Beckman part number 17449). The instrument is operated at its highest sensitivity, i.e., attenuation of one. Column and detector temperature are kept at 125°C. Filament current is 300 milliamperes. The carrier gas is helium and experience has shown that a flow rate of 94 ml per minute gives optimum resolution and good peak height.

*Bristol Dynamaster Recorder* having a maximum response of one millivolt full scale and an operating speed of one-half inch per minute.

*Gast Pump* (Model AD-440) operated by a pack of 3 two-volt Willard storage batteries permitting two hours of continuous sampling. It is a simple, lightweight arrangement (12 pounds) and can be carried by one man on a survey.

*MSA Midgest Impingers* equipped with coarse porosity fritted glass bubblers were used as scrubbers. The scrubbers were selected after careful screening, those being used which yielded the highest recoveries of known concentrations of methylene chloride from a test tank. Methylene chloride was used in these tests because of

its high vapor pressure. The practical assumption was made that a high rate of scrubbing efficiency for this compound would assure reasonable recovery for compounds having lower vapor pressures.

*Spectrographic grade meta-xylene* was used as the scrubbing solvent. This solvent was chosen because of its ready availability, its convenient boiling point and chromatographic retention time. For low boiling organic solvents including those which are most frequently encountered in industrial hygiene studies, this sampling medium has proved satisfactory. It is not suitable for trapping those contaminants whose retention time is in the range of that of meta-xylene.

## Methods

*Method A*.—Air to be tested is scrubbed through two midget impingers in series, each containing 10 ml of meta-xylene. A sampling rate of 0.0133 cubic feet per minute is maintained until 0.1 cubic foot has been scrubbed through the meta-xylene. Although we have sampled as much as 0.2 cubic foot without detectable carryover into a third impinger we have found that both the sampling rate and the volume are critical. A longer sampling period than that required for 0.2 cubic foot of sample may result in loss of contaminant and sampling liquid.

The contents of the impingers are pooled and a 0.05 ml sample of the solution is chromatographed for traces.

*Method B*.—Although method A is an excellent approach, we felt that if it could be possible to increase the proportion of traces which would be trapped during a study by reducing the volume of scrubbing liquid and thus increase the sensitivity of the method. Also, it was thought desirable to see whether a scrubber could be developed which would enable a high order of recovery with only one bubbler. This was made possible by a simple modification of the Australian type bubbler.<sup>2</sup> The result was

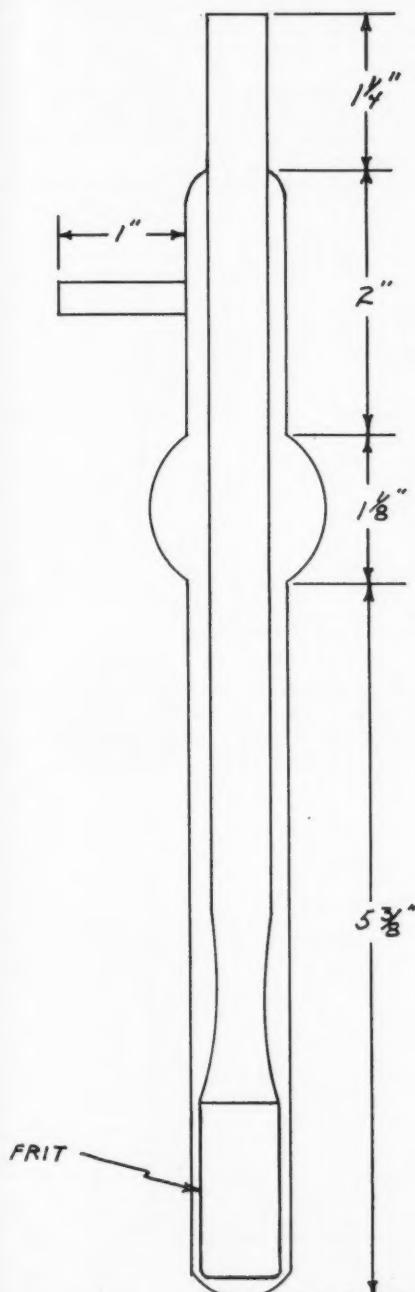


FIGURE 1. Scale drawing of modified Australian bubbler.

a unit which gave from 75 to 80 per cent efficiency and which required a volume of only 5 ml of trapping fluid.

The modification is as follows: A medium porosity fritted glass scrubber which is used with the Greenburg-Smith impinger was sealed to an appropriate length of 10 mm I.D. borosilicate glass tubing. This scrubber then was sealed into a bottle made from two heavy-walled borosilicate glass test tubes 150 mm long, having an inside diameter of 14 mm. The glass frit was

TABLE I  
Data from Four Typical Chromatograms  
of Chlorinated Hydrocarbons

	Methylen-chloride	Carbon-tetra-chloride	Tri-chloro-ethylene	Per-chloro-ethylene
<b>A</b>				
Mean retention time (minutes).....	2.56	5.38	6.85	13.58
n.....	10	10	10	10
SD in minutes.....	0.13	0.03	0.3	0.2
<b>B</b>				
Mean peak heights: 100 ppm in millimeters.....	23.9	20	16.1	9.1
n.....	10	10	10	10
SD in millimeters.....	0.88	0.66	1.0	0.33
<b>C</b>				
Mean peak heights: 200 ppm in millimeters.....	48.3	40	32	17.9
n.....	10	10	10	10
SD in millimeters.....	1.05	0.94	1.05	0.75

TABLE II  
Chemical and Chromatographic Analysis of  
Industrial Atmosphere Samples  
(Benzene Analysis)

Sample Number	1	2
<i>Method:</i>		
Chemical:		
µg benzene: total.....	360	600
ppm benzene.....	19.8	34
Chromatographic:		
peak height.....	4 mm	6.5 mm
ppm.....	20	32

Standards: 50 ppm benzene in 0.1 cubic feet 5 mm  
100 ppm " " 0.1 " " 10 mm

placed as close as possible to the bottom of the bottle and centered. (See Figure 1).

The efficiency of this unit was tested by using two such scrubbers in series, backed up with a midget impinger-scrubber. Sampling was continued until 0.15 cubic foot of air had been scrubbed. Repeated determinations showed that with a flow rate of 0.00706 cfm (200 ml

per minute) the above mentioned order of recovery (75-80%) could be obtained. No methylene chloride was detected in the third scrubber. Increasing the flow rate to 0.0212 cfm (560 ml per minute) reduced the recovery to 50%. However lower flow rates did not improve the efficiency of the system.

Although the volume of liquid injected into

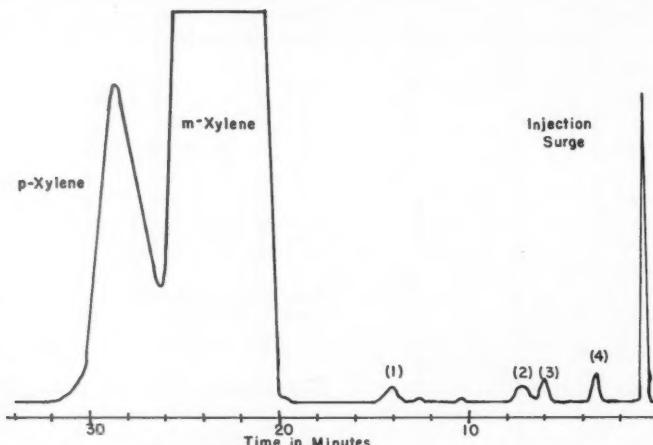


FIGURE 2. Chromatogram of several chlorinated hydrocarbons, using 6-foot Silicone 550 column at 124°C with 25 PSIG and 300 MA. Attenuation 1. 0.05 ml sample. The chlorinated hydrocarbons are shown by the small peaks as follows: (1) Tetrachloroethylene, 100 ppm, (2) Trichloroethylene, 100 ppm, (3) Carbontetrachloride, 100 ppm, (4) Dichloroethylene, 100 ppm.

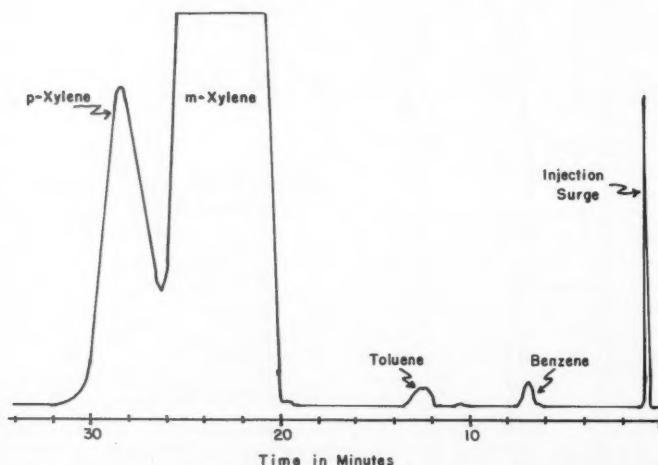


FIGURE 3. Analysis of a mixture of benzene and toluene, using 6-foot Silicone 550 column at 124°C with 25 PSIG and 300 MA. Attenuation 1. 0.05 ml sample. Toluene, 100 ppm, and benzene, 100 ppm.

the chromatograph was kept at 0.05 ml per determination, it was found possible to obtain good peak heights for low orders of traces, using smaller volumes.

A further advantage of the modified bubbler is the fact that it is possible to sample the air

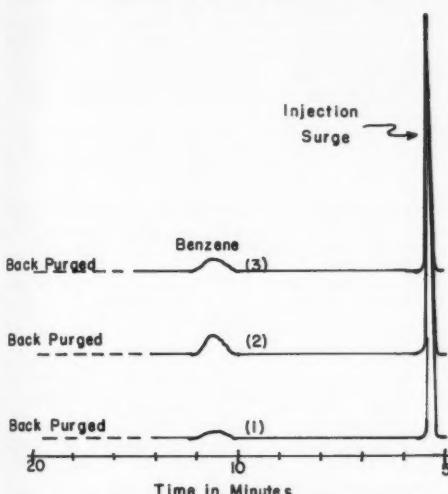


FIGURE 4. Analysis of an industrial benzene exposure, using 8.5-foot Silicone 550 column at 124°C with 22.5 PSIG and 320 MA. (1) Benzene, 50 ppm; attenuation 1; 0.05 ml sample; (2) Benzene, 100 ppm; attenuation 1; 0.05 ml sample; (3) Industrial air sample; attenuation 1; 0.05 ml sample.

using only one scrubber, and still get reasonable information during a survey without the bother which occurs when two scrubbers have to be set up, watched, and managed by one field worker.

Table I shows analytical data obtained by chromatographing air samples containing mixtures of chlorinated hydrocarbons at concentrations of 100 and 200 parts per million each. The standard deviations were calculated from ten separate runs. Figure 2 is a copy of a typical chromatogram obtained from a sample containing 100 ppm each of the chlorinated hydrocarbons shown.

Table II (see also Figures 3 and 4) is a summary of data obtained during a recent industrial study, involving the use of solvents containing benzene. The chemical analysis of benzene was done using the method of B. H. Dolin.<sup>2</sup>

Table III is a summary of the analysis of a

TABLE III  
Quantitative Analysis of Mixture of  
Chlorinated Hydrocarbons

	Peak height mm		Concentration ppm			Recovered %
	Standard	Unknown	Standard	Unknown (theoret- ical)	Unknown analysis	
Dichloroethylene.....	24	123	100	500	512	102
Carbon tetrachloride...	20	9.5	100	50	53	106
Trichloroethylene.....	16	18.5	100	120	116	97

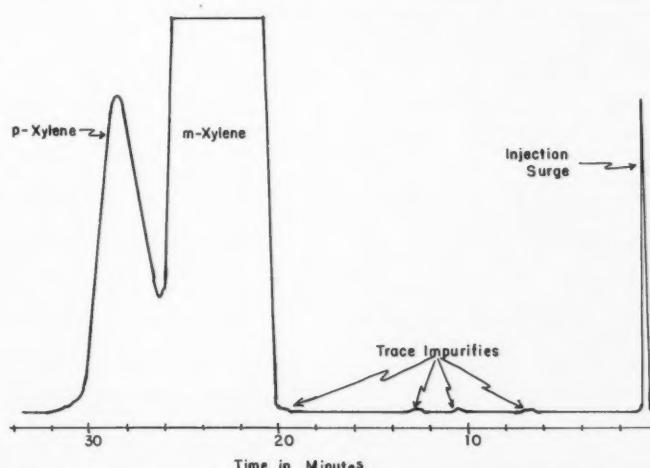


FIGURE 5. Chromatogram of meta-xylene base line, using 6-foot Silicone 550 column at 124.5°C with 25 PSIG and 300 MA. Attenuation 1. 0.05 ml sample.

mixture of chlorinated hydrocarbons prepared by our engineering staff and analyzed in the laboratory with the use of gas chromatography. The recoveries are typical.

The spectrographic grade of solvent does contain traces of impurities (Figure 5). At the sensitivity levels being used these traces do not interfere significantly. However, we feel that if the solvent can be purified further the technique described above can be used successfully to determine even smaller concentrations of traces, by applying the method of C. D. Lewis and associates.<sup>1</sup>

#### Acknowledgment

The authors thank Mr. H. B. Ashe, the Director of the Industrial Hygiene Division for

his guidance and help in the preparation of this paper.

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#### NEW PREFIXES FOR UNITS

THE NATIONAL BUREAU OF STANDARDS has decided to follow the recommendations of the International Committee on Weights and Measures to use new prefixes for denoting multiples and sub-multiples of units. The Committee adopted the prefixes at its meeting in Paris in the fall of 1958. In addition to the eight numerical prefixes in common use, which are given in the table below, the Committee expanded the list by adding the four prefixes marked with an asterisk. Thus, for example,  $10^{-12}$  farad is called 1 picofarad, and is abbreviated 1 pf.

Multiples and Sub-Multiples	Prefixes	Symbols
$1,000,000,000,000 = 10^{12}$	tera*	T
$1,000,000,000 = 10^9$	giga*	G
$1,000,000 = 10^6$	mega	M
$1,000 = 10^3$	kilo	k
$100 = 10^2$	hecto	h
$10 = 10^1$	deka	dk
$0.1 = 10^{-1}$	deci	d
$0.01 = 10^{-2}$	centi	c
$0.001 = 10^{-3}$	milli	m
$0.000,001 = 10^{-6}$	micro	$\mu$
$0.000,000,001 = 10^{-9}$	nano*	n
$0.000,000,000,001 = 10^{-12}$	pico*	p

# Laboratory Simulation of a Hot Industrial Job to Find Effective Heat Stress and Resulting Physiologic Strain\*

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WHEN A JOB involves exposure to a potentially noxious agent the direct and often the best way to assess its effects is to observe physiologic changes which occur among those who are exposed. Environmental heat is such an agent and if one is in doubt regarding strains produced by a particular hot job the best approach is to measure circulatory responses, sweating and body temperature of the workers. When direct measurement is not feasible, one may try to predict degree of heat strain from the extensive physiological literature on effects of exposure under various conditions. This is an account of such an attempt to predict, in which the system of assessing heat stress described by Haines and Hatch<sup>1</sup> and the system of grading strain therefrom, suggested by Belding and Hatch<sup>2</sup> (hereinafter referred to as H&H and B&H, respectively) were utilized for evaluation of an industrial job involving exposure to radiant heat. Application of the systems yielded a large overestimate of heat stress and consequently of resulting physiological strain.

The first purpose of this report is to account for this overestimate, because others who use the systems are liable to the same error. The second objective is to illustrate the usefulness of laboratory simulation for assessing the severity of a hot industrial job when circumstances prevent direct study of the actual workers. The third objective is to demonstrate certain factors which are operative in determining the usefulness of metallic-coated reflective clothing for protection against radiant heat.

## Industrial Field Study

The job with which we became concerned is in a new plant and came to our attention because the first hot weather had brought com-

plaints ascribed to heat exposure. The management wanted to know whether this work should be regarded as dangerously hot.

The first step in obtaining an answer was to assess the heat load generated by the process equipment, the weather and the activities of the worker. This involved collection of information on globe temperature, air temperature, air velocity, level of activity and duration of exposure at each work site. From this information net heat gain to the body by radiation (R) and convection (C) was computed, using the coefficients given by H&H, and the metabolic contribution to the load (M) was estimated. The sum of these was taken as the heat load which had to be dissipated by sweating ( $E_{req}$ ) if a worker were to remain in heat balance.

Secondly, the potential for evaporative cooling ( $E_{max}$ ) was calculated to find out whether the required level of loss could be maintained. Dependent primarily on water vapor pressure of the atmosphere (humidity) and on air velocity, it was computed using a coefficient also provided by H&H.

The third step in the approach was to predict the degree of physiologic strain, using the concepts given by B&H.

From information supplied by supervisors and from direct observations, it was learned that the work of this particular job is equally divided between the first and second halves of each shift. Each half-shift involves: (a) about an hour of light preparatory work, at temperatures about 5°F above out-of-door shade temperatures; (b) the hot part of the job, consisting of 18 work-rest cycles, each lasting about six minutes; and (c) rest, approximately 80 minutes of each half-shift spent in an air-conditioned lunch room.

Observations of the conditions prevailing for (b), the hot part of the job, were made at several locations on two days when air was entering

\* Partial support for these studies was provided by Grant No. RG-4347 from the National Institutes of Health, U. S. Public Health Service

TABLE I  
Average Conditions During Six-minute Cycles  
of Hot Job  
Outside Air Temperature 80°F

Sub-task	Ave. Time seconds	Estimated M BTU/hr	Air Temp. °F	Wall* Temp. °F	Air Speed fpm
A. Moderate to heavy activity....	80	1600	125	180	250
B. Light to moderate activity.....	100	1100	120	165	250
C. Standing at rest.....	60	600	85	120	250
D. Standing or sitting at rest.....	120	500	80	100	400

\* Computed by method of Haines and Hatch<sup>1</sup> from globe temperature, air temperature and air speed.

the work shed at approximately 80°F. Average results are shown in Table I. These indicate that each six-minute cycle involves about three minutes of exposure to a high level of radiant heat. The work is heavy about 20 per cent, and moderate to light 50 per cent of the time; 30 per cent of the time is spent resting at open bays which line the long sides of the shed. From the wetness of the clothing it was obvious that the workers sweat freely, but no signs of overstrain were seen on these 80°F days.

The observations had to be made under the weather conditions prevailing at the time of our visit to the plant, but the interest was focused on heat stress and strain in the hottest weather likely to be encountered. In order to arrive at a definition of this weather, local weather bureau records were consulted. These revealed that the hottest combination of conditions sustained for more than an hour or two was a shade temperature of 90°F and a water vapor pressure of 19 mm Hg (52 per cent relative humidity).

Heat stress in such weather was then predicted on the assumption that work place temperatures would be 10°F warmer than had been observed in the 80°F weather (Table II). Fortunately, the ventilating system of the work shed was such that air speeds could be assumed to remain as measured. On these bases,  $E_{req}$  for the hot part of this job was calculated to be 2600 BTU/hour, a total of 9400 BTU for the 3.6 hours of exposure during each shift. Apparent load during the two hours of preparatory work was about 1000 BTU per shift. Concurrent removal of the 10,400 BTU load that was generated over 5.6 hours would require evaporation of about 4.3 liters of sweat. Production of sweat at this required rate would not represent an overstrain for fit, acclimatized men (B&H).

The large turnover of air, and the fact that

TABLE II  
Estimate of Hourly Heat Load of Hot Part of  
Job\* in 90°F Weather

Sub-task	% of Time	Contribution to hourly heat load (BTU)			Heat load $E_{req}$
		M	R	C	
A.....	22	350	460	290	1100
B.....	28	310	500	340	1150
C.....	17	100	100	0	200
D.....	33	160	60	-60	160
Total.....	100	920	1120	570	2610 BTU/Hr

\* Performed for approximately 1.8 hours each half-shift.

no water is contributed in the production process made it fair to assume that ambient vapor pressures in the shed would be those prevailing out-of-doors. (Measurements had demonstrated this to be true on the 80°F days.) At the maximum predicted vapor pressure of 19 mm Hg and at air speeds prevailing for the hot part of the job,  $E_{max}$  was calculated to be 1990 BTU/hour. This rate of evaporative cooling would be inadequate to dissipate the heat load during the hot part of the job. The deficiency over each 1.8 hour stretch appeared to be 1120 BTU, greatly exceeding the 250 BTU representative of the maximum body heating that is regularly tolerable (B&H). The logical prediction was that performance of this job in hot weather would result in severe overstrain.

That this was actually an overprediction was immediately clear from the fact that in the weather of interest workmen actually had completed two 1.8 hour exposure periods per shift without incurring injury. A suggested explanation for the discrepancy between the prediction and actual experience was that the work clothing was reducing the stress by acting as a shield against some of the radiant heat. To examine this point and to learn more about the actual strain, this job was simulated in our laboratory.

### Laboratory Study

#### Design

The intent of the laboratory study was to approximate the kind and degree of stress that was predicted for this job on a day when the out-of-door shade temperature was 90°F. To accomplish this the general ambient temperature of the hot room was set at 95°F. Exposures were specified for two hours and involved alternate periods of work for four minutes and rest for two minutes. The work was performed in a

wind tunnel through which air was being moved at approximately 250 feet per minute.

The work, which was repeated at 10 second intervals, involved standardized arm and back movements in pulling and releasing a 30 pound weight. It was performed from a fixed stance, while facing a battery of Calrod heaters imbedded in the tunnel wall. Heat intensity was adjusted so that the average temperature of three blackened Vernon globes mounted vertically in the position occupied by the subject was 142°F; at the air temperature (97°) and air speed (250 ft/min) in this position, the mean radiant temperature was calculated to be 205°F.

During the two-minute rest of each cycle subjects sat in a corridor outside the wind tunnel. Here, both air and wall temperatures were 95°F, and air speed was 400 ft/min. A comparison between the situation predicted for the industrial job on a 90°F day and the situation created in the laboratory appears in Table III. Note that the predicted total heat load at work and at rest in the laboratory (derived using the H&H system) corresponded well with the prototype field situation. In the laboratory model, this was accomplished with a somewhat smaller fraction of metabolic and convective heat and somewhat larger of radiant.

The subjects were three young men, aged 20, 20, and 28. They were acclimatized for work in the heat.

Initially, effects of three levels of ambient vapor pressure and three types of clothing assemblies were sought, using the three subjects. Accordingly, a Latin Square design calling for nine exposures was used. The three vapor pressures originally specified were intended to include one situation in which evaporation was predicted to be adequate for maintaining heat balance (17 mm Hg) and another in which it was not (22 mm Hg), in addition to the level of critical interest in the actual industrial situation (19 mm Hg). Failure to find that limit on evaporation was critical, even at 22 mm Hg, led to trial of 25 and 27 mm Hg levels. This involved a second Latin Square arrangement using the data already collected at 22 mm Hg.

The three clothing assemblies were specified in order to obtain comparative data on ordinary as well as metallic-coated clothing, and on metallic-coated clothing which permitted two degrees of ventilation of the skin. Seminude status was specified in a collateral series to achieve a direct demonstration of blocking effect of ordinary clothing against radiation. The four assemblies are described below:

(a) *ordinary work clothing*, consisting of cotton khaki shirt and trousers, long

TABLE III  
Estimate of Average Heat Load on the Actual Job on a 90°F Day and in the Laboratory Study

		Actual job	Laboratory study
Duration (hours).....		1.8*	2.0
Cycle time (minutes)	work....	4.0	4.0
	rest....	2.0	2.0
	both....	6.0	6.0
Body heat production (BTU/hour)	work....	760	540
	rest....	160	130
	both....	920	670
Radiation (BTU/hour)	work....	1060	1730
	rest....	60	0
	both....	1120	1730
Convection (BTU/hour)	work....	530	140
	rest....	-60	0
	both....	570	140
Total heat load (BTU/hour)	work....	2450	2410
	rest....	160	130
	both....	2610	2540

\* This is for each half-shift and neglects prior one hour of light work with heat load equivalent to about 500 BTU.

cotton underdrawers, tee shirt, cotton cap, cotton work gloves, cotton socks and leather shoes, and dark glasses;

(b) *reflective apron assembly*, with knee length metallic-coated asbestos apron and knee-length leggings (the latter open down the backs of the legs to favor ventilation), over items of outfit (a), except that cotton shorts were substituted for long underdrawers;

(c) *reflective coat assembly*, with knee-length metallic-coated asbestos coat, knee-length leggings wrapped completely around legs and hard hat, over items of outfit (a), except that cotton shorts were substituted for long underdrawers;

(d) *seminude assembly*, with socks, shoes, shorts, gloves and dark glasses only.

Results of the physiological study were used to furnish a check on predicted heat stress that was calculated from environmental conditions and measurement of the heat produced in performing the work. The result of each exposure was production of sweat, with or without heating up of the body tissue. When the sweat was evaporated from the skin we knew that about 2.3 BTU of heat was removed from the skin per gram because this is the heat of vaporization of water at 95°F. The amount of sweat evaporated was considered to be represented by

the gross loss in clothed weight during exposure. Suitable correction was made for weight of water imbibed. This method yielded overestimate of evaporative cooling to the extent that sweat dripped off or was evaporated from the clothes instead of the skin. Obviously, any part of the sweat which stayed in the clothes was ineffective for cooling. In cases where there was storage of heat in the body tissues, indicated by rise in body temperature, the amount had to be estimated and added to the evaporative heat loss to obtain actual heat load. Storage was calculated from average rise in body temperature (skin temperature weighted 1/5, rectal 4/5)  $\times$  body weight  $\times$  specific heat of body tissue. In these studies, storage was negligible except under the most difficult combinations of conditions.

Recovery pulse rate, the average of 30-second counts taken one minute after each four-minute work period, was used as a measure of circulatory strain. The rates obtained were adjusted to compensate for individual differences between subjects. Nude weight loss + weight of water imbibed was the measure of sweat. Fatigue was indicated on a point scale, with five points indicating inability to continue.

#### Protection with Ordinary Work Clothing

Heat stresses and strains of exposure at various vapor pressures in ordinary work cloth-

ing are given in Table IV.  $E_{req}$  of this work was predicted to be 2540 BTU/hour. The actual heat load appears to have been about 1740 BTU/hour, only 69 per cent of the prediction, suggesting error in estimate of M, R or C in making the prediction. M, determined by sampling of oxygen consumption, and C, negligible under these conditions because skin temperature and air temperature were both about 95°F, were not subject to important error. Therefore, R could have been no more than about 1070 BTU/hour, 62 per cent of its predicted value (cf Table III). It appears that this ordinary work clothing blocked nearly 40 per cent of impinging radiation.

With the actual heat load at 1740 BTU/hour evaporative capacity should become a critical factor at vapor pressures above 22 mm Hg. The physiological data indicate that strain was unaffected at vapor pressures from 17 through 22 mm Hg. At 25 mm Hg rectal temperature rise and recovery pulse rate were significantly higher as was fatigue. Sweating and wasted sweat were not increased until the next higher level, 27 mm Hg, was reached.

In a collateral study, an attempt was made to demonstrate the protective effect against radiation more directly, by exposing the subjects to the same radiation source while seminude and clothed and comparing the actual heat load in the two cases. The level of radiant heat used in the previous exposures was found to be intolerable when seminude, (furnishing qualitative evidence of blocking effect against the radiant load). Results obtained after radiation had been reduced to a tolerable level are summarized in Table V. Here, blocking of about 30 per cent of impinging energy resulted from the wearing of ordinary clothes. The resulting decrease in strain was significant.

#### Heat Reflective Clothing

Effects of wearing metallic-coated clothing on this job were studied because of interest in their practical usefulness for decreasing strain. The reflective apron outfit seemed sensible because it covered most of the area directly exposed to radiation, and appeared to provide minimum interference with evaporation. The outfit with reflective coat and accessories promised somewhat more protection, but at the cost of an unknown amount of interference with evaporation.

Results are summarized in Table VI. The predicted heat load of 2540 BTU/hour again was the result of 680 BTU contributed by M and a superimposed 1760 BTU by R. The average protection against radiation of ordinary work

TABLE IV  
Heat Stress and Strains of Performing a Hot Job  
in Ordinary Work Clothing

	Ambient vapor pressure mm Hg				
	17	19	22	25	27
Heat stress					
predicted heat load.....	2540	2540	2540	2540	2540 BTU/hr
predicted maximum evaporation.....	2170	1990	1730	1480	1300 "
actual heat load.....	1880	1680	1720	1680	(2120)* "
Heat strains					
sweating.....	2160	2170	2240	2170	3040 "
wasted sweat (in clothing).....	280	480	520	480	920 "
rectal temperature rise.....	-0.2	0.0	+0.2	+0.5	+0.7 °F/2 hrs
skin temperature.....	95.1	94.5	95.5	95.0	95.4 °F
recovery pulse rate.....	97	92	94	106	102 per min
metabolic heat production.....	660	680	660	700	800 BTU/hr
fatigue after 2 hours.....	+	+	+	++	++

\* Overestimate of load due to drip off of sweat.

clothing, in this case averaging 39 per cent, was raised to 52 per cent by use of the reflective apron and to 66 per cent by use of the reflective coat.

That the advantage of such clothing is not necessarily proportional to the protection which it provides against radiation is indicated by the observations on strain. Sweating, recovery pulse rate and fatigue were somewhat less in the reflective apron than in the ordinary work clothing. In the lower range of vapor pressures, strain in the reflective coat was about equal to that in the ordinary work clothing, but at higher vapor pressures the reflective coat caused significantly greater strain.

### Discussion

Had sole reliance been placed on results of the plant study and predictions of heat strain by the method of B&H, this job would have been classed as overly stressful in hot, humid weather. In fact, at 90°F and 19 mm Hg the Heat Stress Index (HSI) value for the hot part of the job was 155 (100 is supposedly the maximum regularly tolerable for a full shift), and the predicted tolerance time for the work was a maximum of 16 minutes at a time. Industrial experience belied the prediction and the laboratory study indicated the source of the error. In terms of HSI the real stress was about 85.

In view of the fact that ordinary clothing, regardless of its color, has a very high absorptive efficiency for long-wave radiation of the type used in this study, explanation of the observation that such clothing actually blocked 30 to 40 per cent of impinging radiation is in order. The principle involved was originally established in studies of the efficiency of electrical heat supplied to flying clothing, and has been cited by Burton<sup>3</sup> as applicable for determining efficiency of evaporation of moisture from clothing. When heat is released or taken up in clothing the efficiency for warming or cooling the skin is indicated by the ratio:

insulation outside locus of  
release or uptake of heat  
total insulation over skin

The total insulation of ordinary work clothing will be provided by (a) air trapped in the fabric and between the fabric and skin, and (b) the film of air overlying the fabric. Thus, to account for a 60 per cent transmission for impinging radiation, as in Figure 1, it is only necessary to assume absorption near the surface of the fabric, and to assume that 0.4 of the insulation lies under the locus of absorption and 0.6 over, the latter being attributed largely to air film.

TABLE V  
Effect of Ordinary Work Clothing on  
Radiant Heat Load

	Seminude	Clothed	
Predicted Radiant Load	1240	1240	BTU/hr
Apparent Actual Radiant Load (evaporation + storage - metabolism)	1800 + 80 - 680	1480 + 40 - 680	
total	1200	840	BTU/hr
Load Blocked by Clothing % blocked	40 3	400 32	BTU/hr %
Evidence of Strain sweating	1840	1760	BTU/hr
work and recovery heart rates	105 - 91	96 - 86	per min
rectal temperature rise	-0.4	-0.2	°F/hr
mean skin temperature	96.2	95.2	°F
skin circulation required to remove metabolic heat	1.7	1.2	liters/min

TABLE VI  
Heat Stress and Strain of Two-Hour Exposures  
in Three Clothing Assemblies  
(Heat in BTU/hr)

	H <sub>2</sub> O Vapor 17-22 mm Hg			H <sub>2</sub> O Vapor 22-27 mm Hg		
	Ordinary Work	Reflect. Apron	Reflect. Coat	Ordinary Work	Reflect. Apron	Reflect. Coat
Predicted Radiant Load	1760	1760	1760	1760	1760	1760
Actual Radiant Load (evaporation + storage - metabolism)	1000	760	640	1160	940	580
Protection against Radiation	760	1000	1120	600	820	1180
per cent protection	43%	57%	64%	34%	47%	67%
Sweating	2000	1780	2100	2480	2260	2400+*
efficiency for cool- ing =						
load sweat × 100	84%	81%	63%	74%	72%	53%
Recovery Pulse Rate (per min)	92	87	91	100	97	100+
Fatigue after Two Hours	++	+	+++	+++	++	+++

\* Exposure at 27 mm Hg was terminated after one hour because of overstrain.

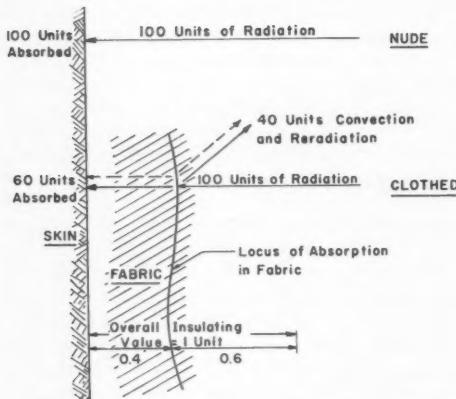


FIGURE 1. Diagrammatic cross-section through skin and clothing to show factors affecting efficiency of protection against long-wave radiant energy.

Then,  $0.6/1.0 \times 100 = 60$  per cent. (In this situation the absorption level probably was closer to 95% than 100% because the Calrod heating elements were radiating partly in the visible spectrum, in that they appeared dull red.) Other studies indicate that this model is entirely reasonable. Since air speed affects both the insulation of the clothing itself and of the overlying air film we may assume that the blocking efficiency of about 40 per cent seen under the condition of this study may have a range of 30 to 50 per cent for most work clothing used at most air speeds. Clothing also blocks transfer of heat by convection, not considered here because there was no temperature gradient between skin and air. Inward convection undoubtedly occurred during performance of subtasks (a) and (b) of this industrial job. Evidence from other sources indicates that the ratio of blocking of convective transfer with this amount of clothing may be about the same as for radiation. On this basis it is provisionally recommended that values for  $R$  and  $C$  computed by the system of H&H be multiplied by 0.60 when workers are covered with light clothing. This is logical because the coefficients of H&H were adopted from studies on nude men.<sup>4</sup>

The accumulated evidence from other physiological studies (cf. references given by B&H) indicates that the peak requirement of this job for energy expenditure, for circulation of blood to the skin, and for sweating will not be excessive as long as the heat load does not exceed the capacity for evaporative cooling. However, conclusions from the re-creation as regards

strain of the real job must be hedged. The laboratory study involved about half as much exposure time and less than half as much work per day as was performed on the real job. Furthermore, the laboratory situation did not simulate the extreme air temperatures possible for a few hours at a time sometime during the summer, the conditions in an emergency which required extra work, or the cumulative effects of a prolonged heat wave.

The margin of safety in the laboratory study appears to have been about 250 BTU/hour, based on the difference between the actual heat load of about 1740 BTU/hour and the  $E_{max}$  of 1990 BTU/hour predicted at 19 mm Hg. This margin would allow any one of the following: an increase in air and wall temperatures of at least 5°F; a rise in ambient vapor pressure of 3 mm Hg; an increase in work level of 50 per cent; or an underestimate of the actual heat load or overestimate of  $E_{max}$  amounting to 12 per cent. The margin of safety is further augmented by the fact that 250 BTU of unbalance will be tolerated from time to time.

Nevertheless, the strain of this job is large relative to the margin of safety. The complexities and uncertainties of prediction of strain from information limited to environmental measurements and observation of the activity serve to emphasize the real need for measurements of strain directly on the workers, on the hottest days, before making confident statements regarding risk to health.

The study of effects of metallic reflective clothing in some respects is not an adequate basis for generalization. Under the circumstances of use, greater protective effect against radiant heat was the prediction.<sup>5</sup> That the protection was at the 65 per cent rather than the 80 to 90 per cent level may be surprising. Burton<sup>6</sup> has reported finding that below a critical size metallic particles do not reflect long-wave energy (e.g., finely divided platinum is "black"). In some applications the binder used to assure adherence of the metal to the fabric, or a covering lacquer has itself been a poor reflector for long wave-length radiation. It has also been demonstrated that the presence of even a thin film of oil or dirt (not present in these tests) can destroy the reflectivity.

For protection against very high levels of radiant heat over periods of minutes, design of metallic reflective overgarments so that they will permit ventilation and consequent evaporation of sweat is not critical, and in fact such design may be contraindicated if air temperatures are expected to be very high. However, for exposures measured in hours, design to per-

mit evaporation of sweat is all-important. In the present studies a net decrease in strain with reflective clothing was noted only with the reflective apron assembly, and this decrease was scarcely enough to justify provision of aprons for this job because experience has shown that extra items of protective clothing fall into disuse unless the advantage which they give is clearly felt by the users.

### Summary and Conclusions

Laboratory simulation of environmental and work conditions of a hot industrial job revealed that resulting heat strain was substantially less than had been predicted by the index of Belding and Hatch. This was attributed to blocking of about 40 per cent of impinging radiation by the ordinary work clothing that was worn. This blocking effect should be taken into account in future use of the Heat Stress Index.

The laboratory analysis indicated the probability that this particular industrial job is physiologically safe, but that the margin of safety is too narrow for full reliance on this estimate. Confidence in this prediction would best be in-

creased by making simple physiologic observations on actual workers under the hottest weather conditions.

Metallic reflective clothing provided some additional protection against heat load. When such clothing is to be worn for periods of hours, it was shown that the design must permit good ventilation as a means for achieving evaporation of sweat; otherwise such clothing may give rise to more strain than ordinary work clothing.

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### CLOUD HEIGHT DATA ANALYZER

THE NATIONAL BUREAU OF STANDARDS has developed a special-purpose computer for the Weather Bureau to analyze data received from a ceilometer, or cloud height indicator. On command, this small-scale data processor will tell an operator not only what the cloud height is at present, but what the highest, lowest, or predominant height was at any time in the last ten minutes, or how often clouds occurred below some critical level during this same period.

A search light revolves to give a vertical scan and throws a modulated frequency beam which is reflected from the clouds to a synchronized photocell. The cloud height is computed from the beam angle at maximum signal to the photocell, and the height is recorded on a 100-space magnetic drum memory. Ten scans are made each minute, hence at the end of ten minutes new data begin to replace old data on the memory drum. There is a short period between scans during which data is analyzed by the computer. Data is always updated to the most recent ten minutes.

# Factory Heat Waves Can Be Broken\*

B. R. SMALL

*Aluminum Company of America, Pittsburgh, Pennsylvania*

TRAVEL throughout America brings to view every day new industrial buildings that reflect much functional progress. New standards bring dignity, beauty, minimum roof heights, frequent absence of windows, compact shapes and much improvement in working conditions.

As such a new plant comes into view, one may ask, "What is its ventilation plan?" An aerial view of the mechanical roof garden with its variety of dust collectors and fan houses could tell us wonders. Modern plants do raise many new problems and broader demands for ventilation systems to assure good working conditions. Industrial ventilation carries an important responsibility. Summer working conditions can no longer be permitted to choke production and profits.

Before discussing a limited appraisal of heat relief practices and some examples we should narrow this subject. Let us omit natural ventilation and simple fan driven roof ventilators. Let us likewise omit the tremendous field of industrial air conditioning and the use of refrigeration as a source of cooling.

## Ventilative Cooling

The cooling agent with which we are concerned is plain outdoor air that is mechanically supplied and distributed in measured quantities in ways to give maximum comfort within factory areas. Because it is supply air we can call the operation "ventilative cooling," and it comprises part one of this memorandum.

It affords a realistic degree of comfort at a sensible cost that is commensurate with heavy industry and many branches of light manufacturing wherever the process, the skills and the economic value do not merit air conditioning. In the presence of indoor heat, the building obviously can never be cooled below outdoor temperature, but this supply ventilation can hold down the room dry bulb temperature within 2, 4 or 6°F of that outdoors, depending upon requirements. It is a moderate program and its objectives are modest.

The real benefit comes in providing air circulation and air motion by means of some duct-

work. Velocities of 50 fpm to 200 fpm directed toward the man suffice for light stand-up operations. Obviously if air motion is to be effective and provide cooling benefits, it must be controllable. Grilles should have vertical vanes behind and horizontal vanes in front that are lever actuated by a chain from the floor with spring return movement. Likewise, circular diffusers should have built-in directional controls that are chain operated.

Large blower-type unit heaters, say 20,000 cfm, give a good spread of air distribution if a 50-foot long duct and grilles are used on each side. Of course, central fan systems of 50,000 to 100,000 cfm excel in better coverage of large floor areas, conversion to evaporative or mechanical cooling facilities, and ease of maintenance.

Concrete examples and information on what is being done and how, and with what results are of great interest. Consider a typical continuous curtain wall, i.e. windowless building of the type that is now predominating in factory construction. Besides being the most economical to build and to maintain, these buildings are the warmest in winter and keep out solar heat in summer. In terms of size these buildings are being built to unprecedented dimensions in order to accommodate the large scale operations of mass production industries. Conventional ventilating doors and roof exhaust ventilators no longer suffice.

Three such plants have been built by the Aluminum Company of America, another is being built and one is in prospect. The first such plant was a screw machine products plant, which was followed by a foil products plant and later by a mill building.

Fresh air is delivered to these plants through the roofs at locations and in amounts as dictated by the indoor heat release. A sheet metal connector extends down four to eight feet below the roof and a circular air diffuser is employed having a chain adjustment from the mill floor. The radial air pattern can be adjusted for blowing vertically downward, out at 45° or outward horizontally, as desired, in cooler weather.

For this application by far the most economical means of roof supply is the low or hood-type roof ventilator. For instance, this year a 42-inch

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diameter 15,000 cfm all-aluminum model directly connected to an 870 rpm two-horsepower motor was bought complete with connector and 40-in. diffuser for about \$1150, to which roof framing, wiring and starter will add \$200 in a new building. This complete job will amount to nine cents per cfm. This type of ventilator has gone a long way toward making a windowless building more feasible. Quantities of air needed are based on internal or live load heat sources. For instance, we will need 500 cfm for every horsepower of net load (some motors are only half loaded) which allows for a 5° air rise.

For inspection, packaging, or other areas where there are no motors, 1½ to 3 cfm per square foot of floor area will provide a little circulation. A supply ventilator would be located on 87 foot centers if 2 cfm is used, and the resulting capital cost would be 18 cents per square foot of floor area, an acceptable figure in many operations.

While on this subject of ventilative cooling the fact must not be overlooked that in most plants one-eighth to as much as one-half of the total summer volume of ventilative cooling air will be urgently required for winter demands. This obvious summer-winter combination affords a full twelve month's usage and the capital costs are distributed accordingly.<sup>1</sup> Many companies are turning increasingly to such systems. Table I lists one company's installations, describes their nature and designates those featuring evaporative cooling.

It is a true saying, and worthy of all industrial hygienists, that make-up air is an essential part of every exhaust system. It is also true that these building exhausts are at the root of most complaints directed against cold air drafts and heating deficiencies.

Thus, through advance planning, the same ventilative cooling equipment can be used all winter on make-up air service by adding heating coils, controls and piping. Such an installation is Alcoa's screw machine products plant at Lancaster, Pa., where roof air supply ventilators in summer are supplemented by central system air for summer and winter. Each long duct carrying 65,000 cfm serves a 160-foot wide zone throughout its length. Machine departments require more air concentration (Figure 1).

Fortunately, today one is no longer handicapped by lack of steam from overloaded boiler plants. A new freedom of use has come about, through the full acceptance by all parties concerned, of direct-fired air heaters that require only gas or fuel oil. These fuels are generally competitive with coal steam costs.

TABLE I  
Typical Outside Air Systems\*

(A) Winter Make-Up Air Only		
1942	Sand Foundry—Unit Heaters in Trusses	100,000 cfm
1942	Sand Foundry—Unit Heaters in Trusses	80,000 "
1943	Magnesium Foundry—Unit Heaters at Side Walls	120,000 "
1946	Electro-Chemical Department—Central System	80,000 "
1947	Specialty Ware Plant—Unit Heaters in Trusses	144,000 "
1948	Permanent Mold Foundry—Unit Heaters at Side Walls	60,000 "
1948	Specialty Ware Plant—Central Station	120,000 "
1950	Electro-Chemical Department—Central System	24,000 "
1953	Foil Mill	50,000 "
1958	Ingot Casting Department—Oil Fired Indirect Heaters	72,000 "

(B) Combination Winter Make-Up And Summer Air Distribution		
1944	Ingot Casting Department—2 Central Systems	160,000 cfm—EC
1947	Ingot Casting Department—2 Central Systems	210,000 cfm—EC
1947	Sheet & Plate Mill—3 Central Systems	315,000 cfm—EC
1954	Screw Machine Products—3 Central Systems	M 130,000 or S 195,000 cfm
1955	Foil Products—Unit Heaters in Trusses	M 80,000 or S 160,000 cfm
1956	Foil Products—3 Central Systems	195,000 EC
1956	Ingot Casting Department—Central Station	105,000 cfm—EC
1959	Metal Coating Building—3 Gas Fired Air Stream Heaters	45,000 cfm

EC—Evaporative Cooling with air washers.

S—Denotes Summer Air.

M—Denotes Make-Up Air.

\* Aluminum Company of America

In addition to the popular industrial version of a warm air furnace, in sizes up to 25,000 cfm there is a second type: a gas-fired heater for use in selected applications having burners that operate directly in the air stream at nearly 100% efficiency. Recirculation of room air must be avoided, likewise possible explosive atmospheres.

#### Radiant Heat Shielding

The second part of any heat relief program should be radiant heat shielding. Radiant heat is a subtle force and is often the actual source of discomfort. Mr. George F. Haines, Jr., well expresses his findings.<sup>2</sup>

"Of all the uncomfortable heat exposures I

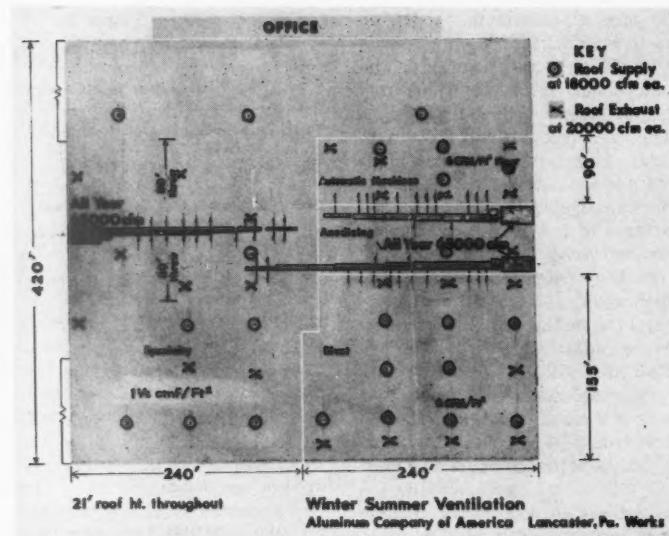


FIGURE 1. Plant make-up air for winter is heated and distributed by two of the three central systems diagrammed. In summer the three systems are augmented by roof supply fans to deliver 6 cfm/ft<sup>2</sup> floor area in machine areas, elsewhere 1 1/2 cfm/ft<sup>2</sup>.

have experienced in the steel and glass industries, I have never seen a case where radiant heat was not the major offender, yet thousands and thousands of dollars are spent year in and year out treating the hot air which usually accounts for less than one-third of the total heat load imposed on the man anyway. I have seen cases where it was obviously ridiculous to provide more general ventilation and so local mancoolers were improperly installed blowing 90-110° F air directly over the man at velocities as high as 1500 fpm; still the radiant heat, which was the major offender, continued to blaze on entirely uncontrolled."

The intensity of heat radiation from the hot surfaces of any common material might well be termed shocking. Some preheating furnaces, surprisingly enough, lack insulation in end walls and on one occasion we recorded 400°F surface temperature with a surface pyrometer and a Tempilstik indicator crayon. This 400°F surface emits 700 btu/hr./sq. ft., or four times as much heat as an office radiator. Anyone would question working within four feet of a cast iron radiator on a hot day with the steam turned on.

A material that maintains a highly reflective surface without deterioration from atmospheric conditions makes the best radiation shielding. Some materials tarnish and deteriorate. Alumi-

num sheet or foil are excellent shielding materials in these respects.

Any shield should be arranged to have an intervening air space and, in addition, a minimum of contact surface with the hot steel framework because of high conductivity. Nuts or washers make good spacers.

A reflective shield installed on a billet heating furnace has reduced the temperature of the exposed surface from 500°F to approximately 300°F. The heat radiated is now 30 BTU/ft<sup>2</sup> as compared to 1320 BTU/ft<sup>2</sup> before shielding. Since this reflector is 90 per cent efficient, its heat emission is below the mean radiant emission temperature of the building. The operating people later said, "This shielding is the best thing they have ever done for us."<sup>13</sup> This one sheet at the end of the furnace did more good than man-cooling fans and expensive roof ventilators previously installed. Obviously the cost of mounting such a sheet is insignificant compared to circulating fans, or exhaust fans.

Another striking illustration involved a 280°F vertical surface of considerable expanse. A large aluminum reflective shield was fastened in place 6 inches away. The shield kept cool and came to equilibrium with dramatic effect at a temperature that was only 20°F above room air temperature.

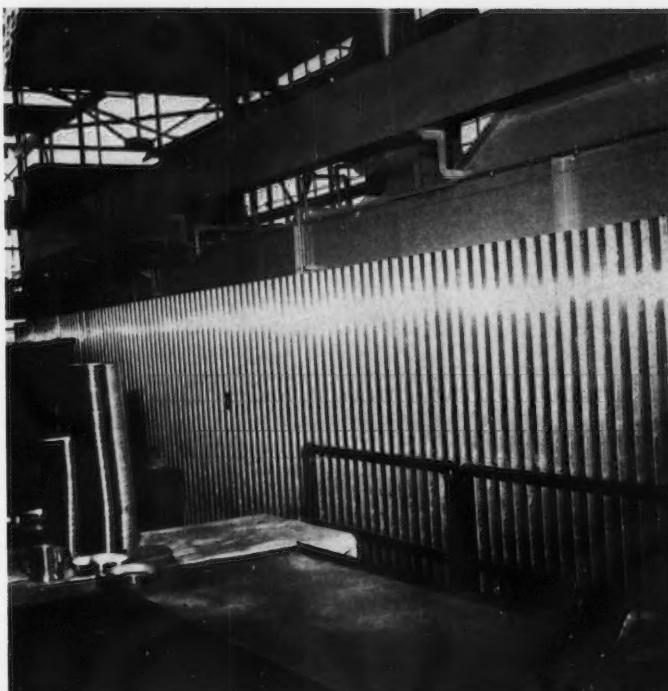


FIGURE 2. Heat shield at degreaser stops radiant heat reaching people at work table in foreground.

At one plant, radiant heat from a large continuous degreasing machine caused discomfort at adjoining work tables. The entire degreaser was shielded with corrugated aluminum sheeting (Figure 2). The essential air space between the heat source and the shield was obtained by mounting brackets which held the sheeting about 12 inches from the degreaser. Writing to us about this installation, the plant engineer said:

"A differential of between 10°F and 20°F now exists between air temperature on either side of the aluminum heat shield. Employees can now work in comparative comfort in the areas adjoining the degreaser. The standard mill finish sheet, used here, has a 90 per cent reflective efficiency. Total cost of the installation, including the steel framework, was approximately \$400. This expense is substantially below the cost of man-cooling fans, hoods, and ventilators that would be required to produce comparable heat relief."

The material installed here was aluminum ribbed industrial siding .032 in. x 41 in. x 72 in.

Common corrugated aluminum farm roofing is also available in large sheets and still has rigidity. Under damaging conditions a one-eighth inch sheet is more lasting.

Many applications are more conveniently served by aluminized fabric used in the form of fixed or spring-roller mounted curtains or draperies, or in the form of protective clothing. A carpenter-style apron of light weight glass fiber fabric is most acceptable for continuous wear because of its unrestricted ventilation. Other types of clothing give broader protection, and even include suits with aluminized asbestos cloth helmet, mask and gauntlets for hot repair work inside of furnaces so hot that a wooden chair on which the man sits exceeds the ignition temperature and bursts into flame.

As a final word on radiant heat protection, don't sell short aluminum paint with its 50 to 60 per cent reflectivity. To paint all surfaces over 150°F (too hot to touch) with high-temperature paint is a most practical form of industrial good housekeeping.

TABLE II  
Effective Temperature and Air Motion

	Still air	300 fpm	700 fpm
Mill air 105°F dry bulb, 80°F wet bulb	88	86½	85
Outdoors 95°F dry bulb, 78°F wet bulb	84½	82	80
Evaporative cooling 82°F dry bulb, 80°F wet bulb	81	77	73
Air conditioned office 80°F dry bulb, 67°F wet bulb	74	—	—

### Evaporative Cooling

The third part of such a heat relief program deals with a more drastic treatment which is finding wider acceptance every year for severe cases, particularly if men are: (a) continuously stationed at a machine, (b) on their feet, and (c) active. Good examples of such cases are: chemical plants, non-ferrous pig and ingot casting, permanent mold and die casting shops, glass forming machines, billet furnaces for forging lines, boiler rooms and turbine rooms.

The solution is often to be found in cooling with washed air. (Table II) This application of evaporative cooling usually requires good air distribution, control, proper air volumes, and grilles placed close to the men, say within four to eight feet, thus permitting smaller volumes and lower costs.

It involves a simple grass-roots method. We

need only recall a hot summer day when a thunder shower comes over and in its wake brings a refreshing drop in temperature. It is a combination of breeze and rain-swept air. For hot operations we can do just as well. Only a spray chamber, a pump to recirculate the same water and a fan are needed, plus some ductwork and grilles. The equipment is simple to operate.

A striking reminder of its value occurred in a high-production hand foundry where molten aluminum was hand ladled into heated molds. Figure 3 shows how the 2500 cfm air stream flows at 1400 fpm velocity from each 10 in. x 30 in. grille that was placed close to the man.

The manager of this Ohio plant told us after the first summer was over that this \$24,000 system serving some twelve men practically eliminated the summer production slump to the extent that the system paid for itself during one extra-hot month that summer. This installation incidentally was the third similar one made in this type of department.

Alcoa's first installation of evaporative cooling was made in 1944 at the company's Lafayette (Indiana) plant in the casting building, which corresponds to an open hearth shop in a steel plant. The superintendent had recently spent time in Arizona and was much impressed with evaporative cooling. The value of two 80,000 cfm systems resulted seven years later in a similar installation for the press and furnace line of the plant's extrusion department.

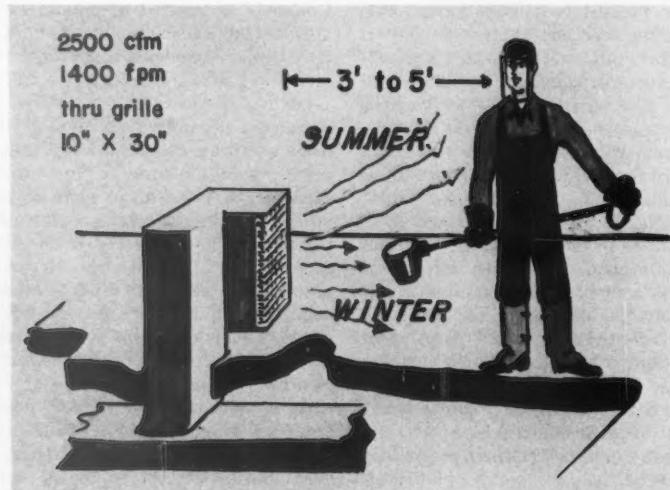


FIGURE 3. Sketch shows ideal arrangement in Ohio foundry for maximum cooling efficiency and seasonal adjustments. Evaporative cooling assures 82°-85°F maximum temperature supply air.

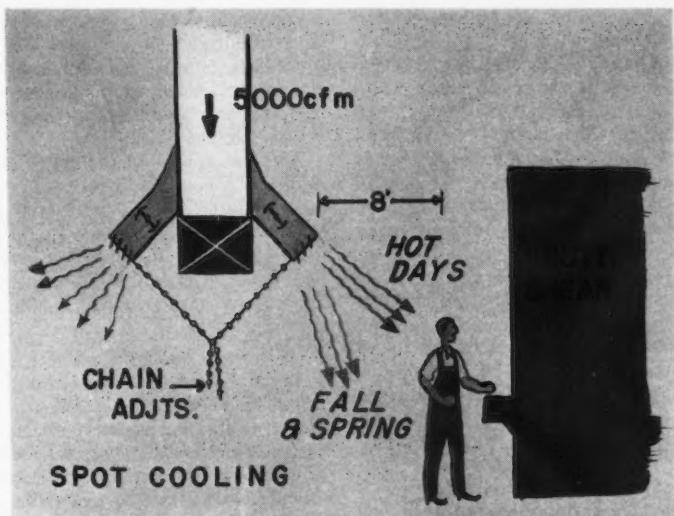


FIGURE 4. Typical downcomer with three grilles totalling 5000 cfm. Operation continues in winter for building make-up air with grilles set for upward deflection.



FIGURE 5. A forging press crew is adequately cooled by inexpensive, 15,000-cfm, desert cooler despite use of recirculated room air.

The second installation at Lafayette illustrates a problem that is typical. A line of extrusion presses with billet heating furnaces and hot metal extended fully across the 500-ft. width of an 800-ft. long building near the center. Roof exhaust ventilators failed to help the interior areas. The air leaving two-bank spray washer at never more than 83°F was carried through an overhead aluminum duct the full 500 foot width. Some thirty-five downcomers were extended within seven to ten feet of the floor. In this manner, overhead stratified hot air is avoided while the horizontal air stream is more effective because it contacts a larger surface of a worker's body than air blowing down or blowing up, as through a floor grating.

All grilles have adjustable horizontal front vanes operated by chain pulls from the floor, and each delivers 2000 to 4000 cfm within 6 to 12 feet of the individual. (Figure 4.) Chain adjustment with spring return is simple to provide and again is most important because good hot weather air motion performance is definitely too drastic for cool weather or even cool mornings. For example, disregarding this essential adjustment resulted not only in general dissatisfaction with one old installation, but also in disinterest in correcting it, so that eventually the ducts were taken out.

An interesting incident occurred in an Ohio plant. Four men worked at a large press, with an adjacent preheating furnace, in a high building that was shy of good low-level air supply openings. A roof air-intake and downcomer would encounter crane rails and many obstructions.

A decidedly unorthodox proposal was submitted by the plant engineer, namely to handle room air through a desert type evaporative cooler. (Figure 5.) As a safety factor, air quantities were doubled to provide 4000 cfm from each of four grilles at an elevation of 9 feet and close to the men. The safety engineer later referred to it most favorably, to wit: "The whole press crew seemingly are very happy with the results." The installed cost with prefabricated duct 16 feet long for 16,000 cfm totalled only \$1500, ready to operate at only 25 to 35 per cent of conventional costs of summer-winter systems.

Except in the hot, dry southwest region, evaporative cooling has definite limitations for industrial applications. But if these three precautions are followed, one can be safe:

(a.) Avoid attempts to cool entire buildings in a wall-to-wall sense. Rather use fresh air supply or air conditioning.

(b.) Avoid light cooling load applications like offices, light assembly areas and repair shops.

(c.) Include roof exhaust ventilators or roof supply units which can introduce some two to four times as much outside air as the air washers are providing. This supplementary ventilation is always essential for the remaining areas of the building.

With observance of the above mentioned precautions, there are no climatic boundaries to hinder effective local and spot cooling installations. Taking 85°F effective temperature in the room as the dividing line, floor areas above this condition will always enjoy positive relief if 82 to 85°F dry bulb air streams can be furnished.

### General

One problem is how to get the ball rolling. As a first step, either for ventilative cooling, radiant heat shielding or evaporative cooling, one needs a survey, plans and cost estimate.

Though literature is available, design standards are few and far between. The wisest course is to call in a consulting engineering firm—one which is known for industrial plant activities—to work jointly with your engineering department. This is particularly important for the first installation. Good firms have an inherent ability to ferret out pertinent data even in unfamiliar fields.

As a matter of interest, the number of engineering firms specializing in air conditioning has increased tenfold since the end of World War II, and their costs have been maintained at an acceptable level.

### Conclusion

In conclusion, let us look upon industrial hygiene and ventilation as an all-around asset to both management and labor.

The changing of a man's work environment can be an effective means to boosting spirit, health and efficiency. It is one of the challenges facing management today. Environmental improvement, when intelligently used, is one of the surest means of increasing a worker's productivity; it encourages employee cooperation and strengthens good will between labor and management.

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# Five Years of Continuous Air Monitoring

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DURING THE five year period, May 1, 1954, through April 30, 1959, a nearly continuous record of particulate air pollution has been kept at a campus site by means of the AISI smoke sampler.<sup>1</sup> The sampler is at an elevation of 200 feet above sea level on the roof of a six-story building which is about 80 feet above the nearest street level. The location is essentially residential in character with an adjacent commercial section. The nearest industrial zone is about two miles distant, with heavy industrialization no nearer than three miles.

In the last four years discontinuity of record has been negligible, only occurring during occasional overhaul of the sampler. Since interpretation of the filter-soiling in units of COH/1000 linear feet of air sampled<sup>2</sup> is partially dependent on sampling rate, that has been checked at monthly intervals when the machine was oiled and checked mechanically. For all data reported, the air flow has been known within five per cent. Experience has shown that the sampler is very reliable if maintenance at the above-mentioned level is given it.

With twelve two-hour samples per day, continuous data for a five-year period may be summarized in a remarkably small space. Table I is such a summary, giving average monthly and

annual information for each of five years. Figures 1 and 2 show respectively: (1) the average of all COH readings by day of the week for each of five years; and (2) the average of all COH readings by hour of the day for the first three years grouped, with the fourth and fifth years individually.

Table II, obtained from other sources,<sup>3</sup> is a monthly summary of traffic flow on the San Francisco-Oakland Bay Bridge, a major traffic artery on which all automotive passage has been fully tabulated for many years. The time period for Table II coincides exactly with that of the monitoring results reported.

In a recent publication reporting particulate atmospheric loading at the sampling stations of the National Air Sampling Network,<sup>4</sup> the Public Health Service pointed out the usefulness of a probability approach for summarizing air pollution data. When applied to the AISI sampler information obtained from a single sampling station in Berkeley, the technique yielded such graphical summaries as those in Figures 3, 4, and 5: Figure 3 shows the data grouped by individual fourth and fifth years and the combined first three years of monitoring; Figure 4 shows the five-year data grouped by certain days of the week; Figure 5 shows the five-year

TABLE I  
Monthly Average Particulate Pollution—COH/1000 ft.

Month	Monthly Average					Base Average Years 1, 2, 3	Year 4	Year 4 Base %	Year 5	Year 5 Base %
	1*	2*	3*	4*	5*					
May	0.7	0.7	0.4	0.3	0.3	0.60	0.29	48	0.34	57
June	0.6	0.7	0.5	0.5	0.3	0.60	0.47	78	0.26	43
July	0.7	0.6	0.4	0.4	0.3	0.56	0.43	77	0.29	52
August	0.5	0.8	0.5	0.5	0.4	0.64	0.52	81	0.42	66
September	0.6	0.8	0.6	0.5	0.7	0.67	0.47	70	0.70	104
October	0.7	0.9	0.6	0.6	0.8	0.75	0.57	76	0.81	108
November	1.0	1.3	1.7	0.7	1.3	1.35	0.74	55	1.29	96
December	1.2	0.8	1.5	1.1	1.7	1.17	1.06	91	1.74	149
January	1.1	0.9	0.7	0.9	0.8	0.88	0.88	100	0.82	93
February	0.7	0.7	0.8	0.3	0.6	0.72	0.33	46	0.57	79
March	0.5	0.5	0.5	0.3	0.6	0.52	0.28	54	0.56	108
April	0.3	0.4	0.4	0.4	0.5	0.36	0.35	97	0.48	133
Year (True Average)	0.71	0.76	0.71	0.54	0.69	0.73	0.54	74	0.69	95

\* 1 = 1954-55; 2 = 1955-56; 3 = 1956-57; 4 = 1957-58; 5 = 1958-59.

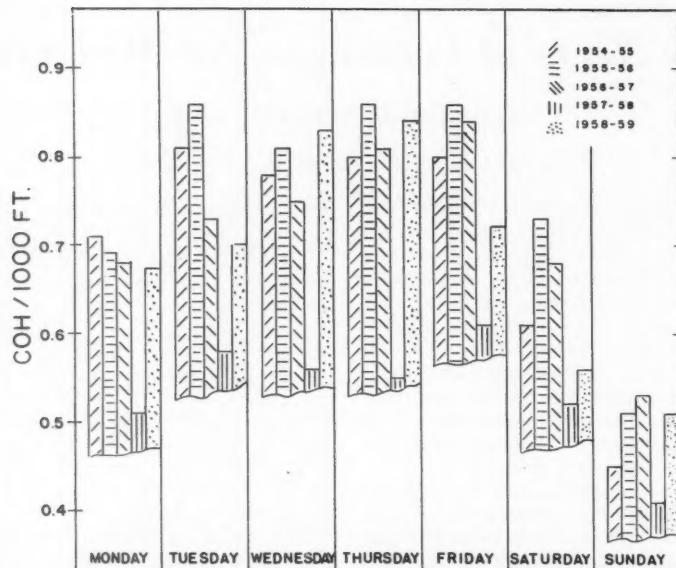


FIGURE 1. Average level of particulate pollution by day of the week for each of five years.

data grouped by the five highest and five lowest months of readings.

For Figures 3, 4, and 5 the sum of COH units for a full 24-hour period (midnight to midnight) was considered as a single datum. Thus the graphs illustrate several possible statistical distributions of an index of 24-hour particulate loading of the atmosphere.

#### Discussion

The use of cumulative frequency plotting at the decile points on a log-normal graph greatly simplifies the comparison of data over various time periods if, in fact, the method reasonably correlates the data. Discussion of the method in *Publication 637*<sup>4</sup> indicates a good application in the case of gravimetric analyses from the National Air Sampling Network. To indicate the applicability for the single monitoring station here reported, Figure 3 shows for the plot of combined years 1, 2, 3, the line of best visual fit and the envelope lines indicating plus and minus five per cent deviation from best fit. It is notable for those data that the decile points fall within plus or minus six per cent except for daily COH values less than three units. Since three COH units per day from a total of twelve sampling periods per day is an average of 0.25 COH units/1000 linear feet (transmission through the filter greater than 97 per cent), the

implication is that for such low observations, the combined sampling and photometric light transmission interpretation of filter soiling are of doubtful accuracy. It is, of course, on such days that particulate air pollution levels are very low. Except for very clean days, then, most of the data are susceptible to correlation by the log-probability method and are internally consistent within approximately the five per cent considered to be the limit of certainty of air flow in the sampling instrument. In this regard, the estimate compares in general magnitude to that of Shephard *et al.*<sup>5</sup> who state from long experience with the AISI smoke sampler that there are non-compensating errors in sampling and determination of at least  $\pm 2.5$  per cent. The level of contamination with which they were dealing was much higher than that reported here. Since for all log-probability plots of data here reported the deviation increased beyond five per cent for low COH readings, the presumed error probably becomes much larger in relatively clean air, and in that case always leads to a low estimate of pollution.

#### Annual Trend

In Table I, the average of all data for each of the monitoring years shows that the first three were essentially comparable. The differences among the yearly averages are practically at

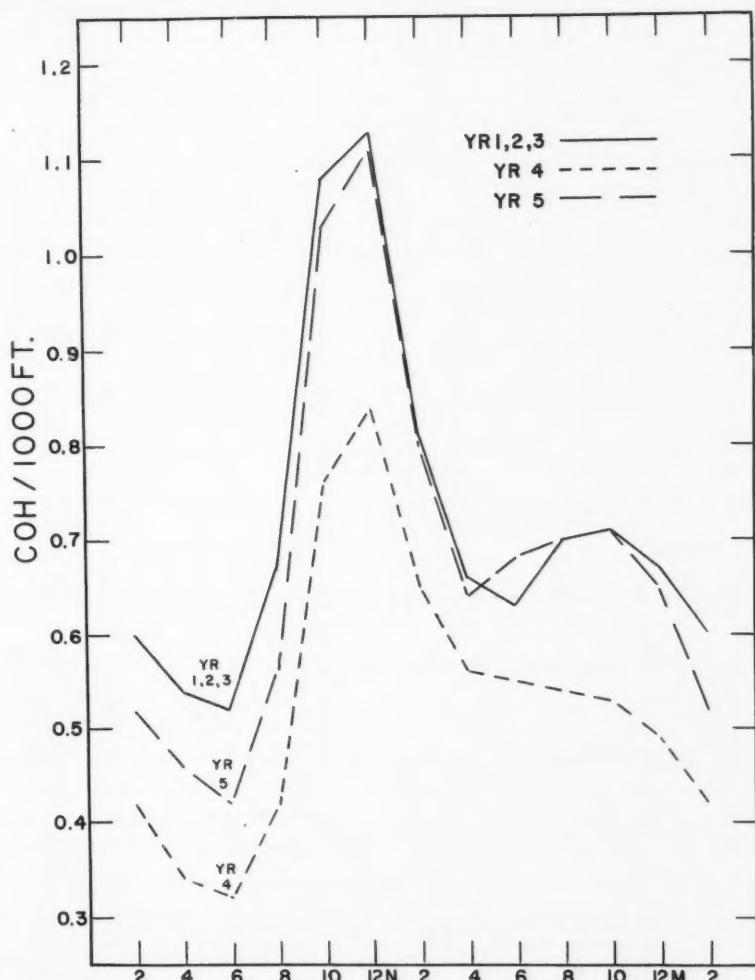


FIGURE 2. Average level of particulate pollution by hour of the day for three baseline years (years 1, 2, 3) and for fourth and fifth years individually.

the previously discussed limit of possible error of measurement. Therefore the average of those three years is considered to be a baseline against which to compare subsequent annual averages. With this presumption in mind it is clear that the fourth year was significantly cleaner than the baseline. In reporting on this fact, Tebbens<sup>6</sup> proposed that the improvement was more related to a meteorologic variation than to reduction of source emissions such as that accomplished by the elimination of open dump burning in the metropolitan complex of which

Berkeley is a part. The fifth year, with a return to nearly the same level of pollution on the average as that of the baseline, supports this thesis. That the meteorologic phenomenon was widespread in effect is confirmed by the statement of Los Angeles Air Pollution Control District<sup>7</sup> that, "Exceptionally stable weather during later part of year contributed to making 1958 worst smog year since 1955." It should be repeated, then, that meteorologic whimsies are of primary importance concerning air pollution phenomena and levels of community air contamination.

TABLE II  
Monthly Traffic on San Francisco-Oakland Bay Bridge

Month	Autos and auto trailers (no passes)					Trucks only (no buses)				
	(Millions)					(100,000)				
	1*	2*	3*	4*	5*	1*	2*	3*	4*	5*
May.....	2.27	2.38	2.43	2.46	2.72	2.10	2.27	2.44	2.44	2.47
June.....	2.28	2.34	2.48	2.54	2.75	2.24	2.38	2.39	2.33	2.50
July.....	2.35	2.44	2.53	2.60	2.73	2.18	2.26	2.35	2.49	2.57
August.....	2.38	2.50	2.59	2.69	2.85	2.26	2.52	2.52	2.51	2.56
September.....	2.29	2.39	2.49	2.55	2.68	2.23	2.37	2.23	2.33	2.57
October.....	2.35	2.47	2.53	2.54	2.75	2.29	2.38	2.59	2.63	2.83
November.....	2.28	2.33	2.44	2.58	2.71	2.24	2.34	2.40	2.35	2.44
December.....	2.29	2.33	2.45	2.58	2.72	2.27	2.24	2.24	2.35	2.63
January.....	2.14	2.23	2.34	2.39	2.53	2.12	2.23	2.37	2.36	2.49
February.....	2.04	2.21	2.21	2.26	2.40	2.00	2.15	2.15	2.11	2.25
March.....	2.36	2.49	2.47	2.59	2.78	2.43	2.43	2.36	2.41	2.70
April.....	2.33	2.38	2.40	2.59	2.66	2.29	2.30	2.42	2.44	2.68
	27.36	28.49	29.36	30.37	32.28	26.65	27.87	28.46	28.75	30.69
Increase per year.....		1.04	1.03	1.03	1.06		1.05	1.02	1.01	1.07

\* 1 = 1954-55; 2 = 1955-56; 3 = 1956-57; 4 = 1957-58; 5 = 1958-59.

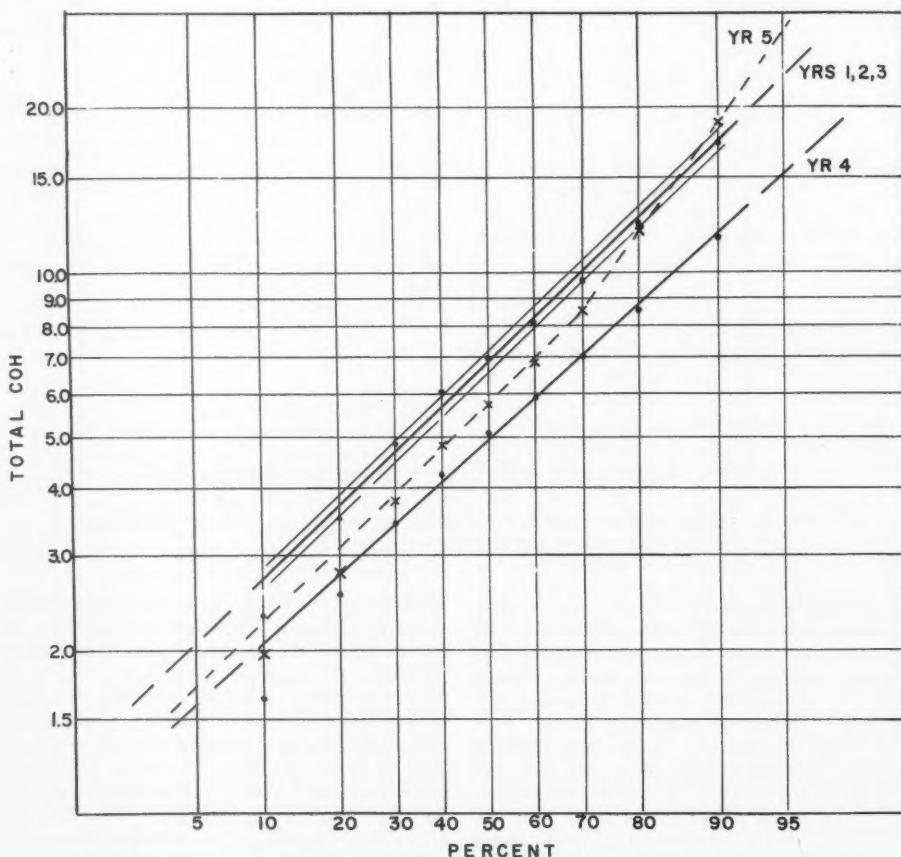


FIGURE 3. Frequency distribution (logarithmic) of daily COH totals for three baseline years (years 1, 2, 3) and for fourth and fifth years individually.

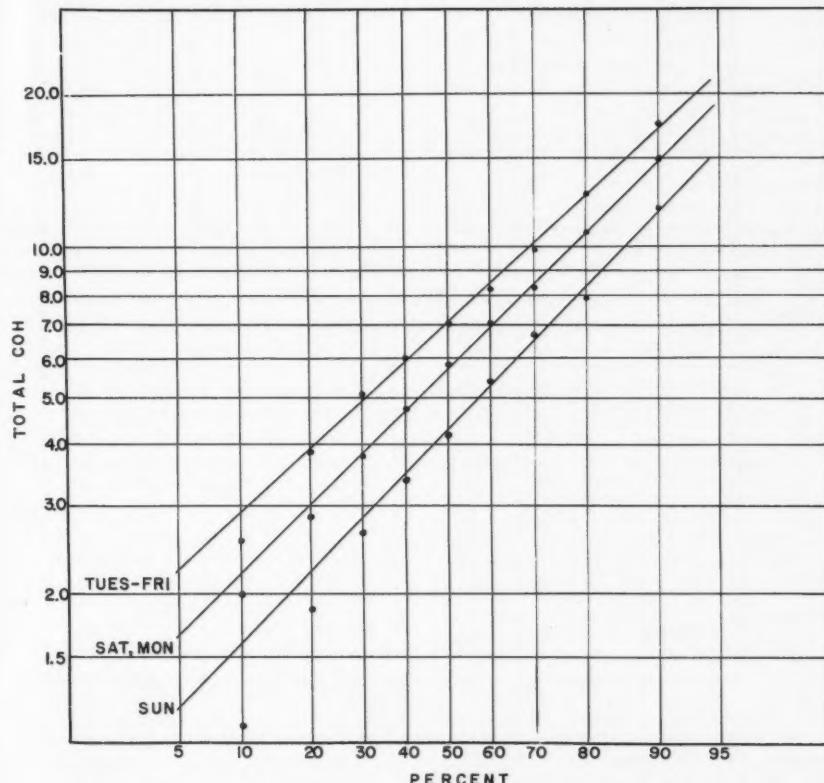


FIGURE 4. Frequency distribution (logarithmic) of daily COH totals for all five years by certain days of the week: Tuesday through Friday; Monday and Saturday; Sunday individually.

On the whole, the data suggest that the annual average of pollution is more nearly stable than trending either up or down. However, as shown in Figure 3, the fifth year data are not clearly susceptible to log-probability correlation by contrast to all other individual years. In fact, one would presume that there occurred a break in the continuity of data during the fifth year. That this happened about September of 1958 is indicated in Table I, where monthly tabulations indicate September as the first of several months whose average was above that of the same baseline months. Preceding September, 1958, sixteen months had shown pollution levels equal to or less than the same months of the baseline years.

By contrast, Table II shows the unmistakable upward trend in such community activities as automobile and truck transportation during the

monitoring period. The increase has been continuous, though not constant, from year to year. During the fifth year automotive passages were eighteen per cent greater than during the first while truck passages had increased fifteen per cent. If automotive transportation per se were crucial in affecting the annual index of air pollution measured by the AISI sampler, such an increase would have been well within the ability of the instrument to measure it and would be evident.

#### Seasonal and Monthly Trends

It has been typical during the five monitoring years that November and December were months of highest particulate air pollution. Not only have the averages of those months far exceeded the others, but also the worst day (24-hour average) of any monitoring year and the

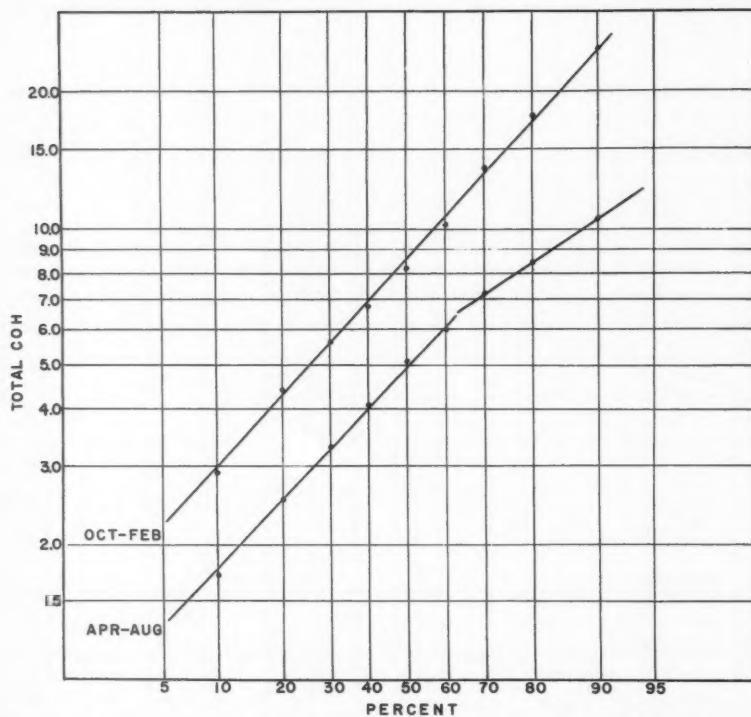


FIGURE 5. Frequency distribution (logarithmic) of five-year COH totals for five highest months (October through February) and five lowest months (April through August).

worst two-hour sample of any year have typically occurred in one or the other of those months. Shown below are the high values of the two measurements as they occurred during those months:

Year	1	2	3	4	5
High day (average)					
November.....	(occurred in January)	3.7	3.4		3.2
December.....				2.3	
High two-hour reading					
November.....	4.0	6.0	5.7	4.3	
December.....					5.7

Although clean days have occurred in all months of the year, the month having greatest frequency of the year's low daily maximum and two-hour measurement is July with six of ten instances. March, April and May share the other instances. These facts reinforce earlier observations from this monitoring effort<sup>6</sup> that the greatest air pollution occurs during seasons with low-

est average winds; the least pollution during seasons of greatest average wind. This observation is in agreement with one of Markee<sup>8</sup> who found in Louisville, Ky., that "... wind speed is the most important variable in the determination of optical density at ground level."

Figure 5 illustrates the differences in distribution of total daily COH units for all days of the five months having highest values (October through February) and of the five cleanest months (April through August). Also notable is the apparent discontinuity of data during the clean months for which no explanation is forthcoming.

#### Weekly and Daily Trends

As has been the case previously,<sup>6, 9</sup> Sundays have continued to be the day of lowest particulate pollution. This is apparent from both Figures 1 and 4. A possibly significant trend, however, is indicated in Figure 1, from which it may be noted that the ratio between the cleanest and the dirtiest typical day, i.e. Sunday/Friday, is approaching closer to unity. That this trend has

been continuous and regular is shown by the following tabulation:

Year	1	2	3	4	5
Sunday average.....	0.45	0.51	0.53	0.41	0.51
Friday average.....	0.80	0.86	0.84	0.61	0.72
Ratio: Sunday/Friday.....	0.56	0.59	0.63	0.67	0.71

Presuming that this trend is real, one must look for an explanation to some non-meteorologic factor, since it is hardly likely that the weather discriminates in any way among the seven days of the week.

One is immediately tempted to implicate traffic increases, yet analysis of several years' tabulation of daily passages of vehicles on the Bay Bridge shows that the proportion of average Sunday to Friday traffic has been constant within a fraction of a per cent. Although transportation comparison of this sort seems to fail as an explanation for Sunday becoming relatively dirtier, the explanation may still lie in the relatively constant increase of traffic, assuming that industrial and commercial activity on Sundays has not increased at the same tempo.

Another observation of interest appears on Figure 2. It is notable that the fifth monitoring year shows a return of daily average data to a bimodal system, i.e. there is again an evening maximum of COH readings. As reported previously,<sup>6</sup> this secondary maximum disappeared during two years, the second of which (1957-58, year 4) was markedly clean. The significance, if any, of this phenomenon awaits further years of monitoring.

As a concluding observation, it is worthy of note that Stern<sup>10</sup> in commenting on results of data from the National Air Sampling Network showed that the Sunday particulate pollution was nearly as great as that of week days. While this has not been the case at the single monitoring station in Berkeley, the trend is toward that situation, with the possible implication that general public contributions to air pollution are becoming more and more a factor in this community problem in the San Francisco Bay area.

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#### WHERE DO INDUSTRIAL PHYSICIANS COME FROM?

**I**N A RECENT ISSUE of *Patterns of Disease*, published by Parke, Davis & Company, the outcome of an unusual, nationwide survey in the medical profession was reported. There are 84 medical schools in the U.S.A. today, although over 450 have existed at one time or another. In the past 16 years, 12 new medical schools have been activated. However, it has been estimated that in the next decade two or three new medical schools per year will be needed to train enough physicians to maintain the ratio of one per 750 population. In this time the number of applicants for medical education is expected to double. Perhaps the most critical problem facing medical education today is the shortage of faculty members, particularly in the basic sciences.

What are the status and the prospects for the training of industrial physicians in this picture of shortage? Will the new schools provide the special training and insight to meet the medical problems of industrial hygiene? What can and should we be doing to ensure an affirmative answer to the latter question?

# A Study of the Relationship of Street Level Carbon Monoxide Concentrations to Traffic Accidents\*

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## Introduction

**I**N GERMANY and the Scandinavian countries, investigators have published extensive observations concerning carbon monoxide exposures insufficient to cause subjective symptoms but which, they report,<sup>1,2</sup> have affected the cardiovascular, endocrine and respiratory systems, the blood and the central nervous system, causing in the latter disturbances of vision and hearing, speech and the reflexes. Since a disturbance of vision and reflexes could be factors influencing traffic accidents, a research project was begun in 1956 to determine whether carbon monoxide as an atmospheric pollutant may have a sufficient effect on the individual driver in urban areas to exert a causal influence on automobile accidents. Concurrently, a second objective of the study was to determine what atmospheric and other conditions would be necessary to create excessive concentrations of CO in the atmosphere. The study was conducted under the auspices of the University of Michigan and the National Sanitation Foundation.

## Organization

In order to have capable guidance in the several areas of this investigation and to assure cooperation on the basis of a knowledge of the whole project, an advisory committee was established. This committee included: Commissioner of Health, City of Detroit; Director, Department of Streets and Traffic; Commanding Officer, Accident Prevention Bureau, Detroit Police Department; Representative of Automobile Manufacturers Association; Director of Laboratories, Detroit Receiving Hospital;

Medical Director, Mayberry Sanatorium; Director of Laboratories, Mayberry Sanatorium; Medical Director, Herman Keifer Hospital; Director of Laboratories, Herman Keifer Hospital; and Professor, Public Health Statistics, University of Michigan, Ann Arbor, Michigan.

The advisory committee was of great assistance in planning various phases of this study. Being associated with the several departments of the city of Detroit and with other interested groups, this Committee extended our own knowledge and facilities related to this research project.

In conducting the actual field work, we had the assistance of several experienced industrial hygienists regularly employed by the Detroit Bureau of Industrial Hygiene. Their services included collection of samples of carbon monoxide in air and operation of the continuous CO recorders, selection of the appropriate method for CO-hemoglobin determination and performance of the actual routine analyses.

The progress of this study was due to the excellent cooperation of several interested departments of the city of Detroit, without whose aid this study would have been impossible. These agencies include: (1) Detroit Department of Health a. Bureau of Industrial Hygiene, b. Receiving Hospital, c. Herman Keifer Hospital; (2) Department of Police—Accident Prevention Bureau; (3) Bureau of Street and Traffic; (4) Public Lighting Commission; (5) Detroit Street Railway.

## Sampling Locations

One of the preliminary steps of this study was to establish sampling stations at selected sites in Detroit which would be representative of the several different types of traffic conditions. The selection of the sampling sites was accomplished after much field testing, deliberation and conferences with various departments of the

\* This study was performed under United States Public Health Service Grant RG-5005 (C). Presented at the Twentieth Annual Meeting of the American Industrial Hygiene Association, Chicago, Illinois, April, 1959.

city of Detroit. Traffic patterns were carefully evaluated and preliminary surveys were made of carbon monoxide concentrations.

*Central Business District (Downtown Detroit).* The recorder located in the central business district was situated on a small triangular island approximately fifty feet on each side. All three sides of the island faced heavily trafficked streets.

*Neighborhood Shopping Area.* This sampling site was in a busy neighborhood shopping area in the northwest section of Detroit. The recorder at this station was placed on the southeast corner of the intersection and the inlet tube was approximately four feet above the street, at the curb line.

*Depressed Highway.* A sampler was located in the building of the R. L. Polk Company's garage which is adjacent to one of the city's depressed expressways. A 50-foot length of tygon tubing was extended from the instrument down into the expressway, the inlet of the tubing being approximately four feet above the ground at the curb line.

*Residential Area.* A recorder was placed in the garage of a home in a residential area in northwest Detroit. Tubing was extended from the instrument to a sampling point in the backyard.

### Instruments and Analyses

#### Determination of Carbon Monoxide in Air

Preliminary surveys of street level concentrations of carbon monoxide at several locations and at different times of day were made with carbon monoxide indicating tubes developed by Dr. Shepard of the National Bureau of Standards and manufactured by the Mine Safety Appliances Company. Up to 250 ml of air was drawn through the tubes with a 50-ml syringe, care being taken to keep the tubes at a temperature above 70°F and at the sampling rate of 50 ml in 30 seconds. Performance of the tubes was considered satisfactory for this purpose, and the values of carbon monoxide found were consistent with those obtained by other methods. On the basis of these results, and other factors, continuous recording equipment and sample sites were selected.

Two Lira Infra-red Gas Analyzers (Mine Safety Appliances Co., Pittsburgh, Pennsylvania) and one Model 105 Tri-non Infra-red Gas Analyzer (Perkin-Elmer Corp., Norwalk, Connecticut), calibrated for carbon monoxide, were used in this study. Their range was 0-100 ppm. Peak concentrations above 100 ppm were thus not

recorded, however this limitation would not greatly influence the median values.

The recording instruments were operated continuously and serviced daily or two or three times weekly, as circumstances dictated. The Lira instrument proved to be more convenient, because it was not influenced appreciably by normal atmospheric water vapor. The Tri-non device required preliminary moisture removal (Drierite was used) from the sample stream.

Instruments were adjusted to zero at each service call with CO-free nitrogen from a compressed gas cylinder and calibrated with 75 ppm carbon monoxide-nitrogen mixtures in compressed gas cylinders (obtained from Mine Safety Appliances Company) or with known carbon monoxide-air mixtures in large plastic bags. Calibrations were made at intervals of one to four weeks depending on the stability of each instrument. All instruments were serviced by experienced industrial hygienists who made appropriate notations on the recording chart at the time of servicing concerning operating status of the recorder, unusual traffic or weather conditions, and other such items. Charts were usually removed monthly after a preliminary comparison of the performance of the instruments on site. Repeated calibration showed these instruments to be reliable to  $\pm 1$  part per million, with infrequent drifting somewhat beyond this value.

Carbon monoxide levels in the driver's breathing zone within passenger automobiles moving in traffic were obtained with a M.S.A. Type 45411 carbon monoxide indicator modified by us to give stable and reliable readings to  $\pm 5$  ppm in the zero to 100 ppm range. Attempts to adapt the recording infrared analyzers to service in a moving vehicle were unsuccessful. Independent spot checks with carbon monoxide indicating tubes agreed well with the continuously indicating analyzer used. Concentrations found ranged from zero to 100 ppm, depending upon traffic and wind conditions. While these concentrations were higher than those found at curb side sampling locations, the differences would not be of physiological significance.

#### Determination of Carbon Monoxide in Blood

All blood samples were collected in Beeton and Dickinson 5 ml vacutainers using di-sodium ethylenediamine tetracetate as an anticoagulant. Tubes were allowed to fill as completely as possible with blood to minimize loss of carbon monoxide to the gas phase. Samples were analyzed within twelve hours to five days of collection. Experiments showed no loss of carbon monoxide during storage for this period of time.

Considerable trouble was experienced in finding methods for determination of carbon monoxide in blood which are accurate in the zero to ten per cent hemoglobin saturation range. A search of the literature revealed 133 methods available for the purpose, which in itself indicates the difficulties involved in successful methodology. A direct spectrophotometric method, a gas volumetric method (Scholander and Roughton, *J. Ind. Hyg. and Tox.* 24: 218, 1942) and a micro palladium chloride method (Berka, *Acta Medica Schadinavica CLII*, 485, 1955), were studied thoroughly. The method of Scholander and Roughton was found to be the most satisfactory for low blood saturation levels and was used to obtain the results reported in this study.

Wide variations in hemoglobin content of the blood of accident victims necessitated a hemoglobin determination in each case to obtain a reliable index of percentage carbon monoxide saturation. Hemoglobin determinations were made with a Hellige Haemometer Model 304, Sahli system.

Reliability of each of the analytical procedures was verified from time to time by analysis of blood of low, known carbon monoxide content. These standards were prepared by appropriately diluting carbon monoxide saturated blood with the same blood free of significant quantities of carbon monoxide. Control analyses made on the blood of persons with no carbon monoxide exposure, smokers and those exposed occupationally gave results consistent with expectations. Our experience with the Scholander and Roughton method in this investigation is in agreement with their reported accuracy of 0.2% volume per cent of CO in blood (one per cent carbon monoxide hemoglobin).

#### Discussion

Researchers have known that variations in carbon monoxide concentrations in the atmosphere near streets can be explained by changes in meteorological and traffic conditions. It has been recognized that, although traffic is the major variable, the meteorological variables of wind speed, wind direction, inversion and temperature must be considered because of their retentive and dispersive effects on gases. What has not been explicitly shown, however, is how each of the independent or explanatory variables is functionally related to the dependent variable; how important each independent variable is, and how well a postulated mathematical relationship explains the variation in carbon monoxide concentration in the atmosphere.

To answer these questions a statistical experiment was conducted in the city of Detroit. Three sample points, or stations, were selected as being representative of traffic conditions in the city—downtown Detroit, a neighborhood shopping area and a depressed highway. At each sample point, for a one month period, two traffic counters recorded the north and south-bound traffic. Concurrently a carbon monoxide recorder charted the carbon monoxide concentration in the atmosphere. The collected data together with the Weather Bureau's published hourly meteorological readings and the International Joint Commission Air Pollution Laboratory temperature inversion data comprised the observations which were subjected to statistical analysis.

#### Statistical Analysis of Environmental Data

The daily median values obtained at the four sampling locations within the city of Detroit for a period of one year showed that at the downtown Detroit location the majority of the readings fluctuated between 5 and 15 ppm. The neighborhood shopping area showed a greater fluctuation with the majority of the observations at that location falling between 3 and 20 ppm. The majority of the observations at the depressed highway location ranged between 3 and 12 ppm. At the residential area location the majority of the observations fell between 0 and 4 ppm.

Figure No. 1 presents days selected at random to illustrate a typical day at each of the four sampling locations. This graph shows the fifteen minute averages and the peak reading within the fifteen minute period. It can be noted that at the depressed highway location the average values were highest in the morning and afternoon rush hours, with greater concentrations in the afternoon. This is most likely due to the location of the sampling instrument in relation to movement of the traffic rather than any difference in traffic or other conditions. The downtown Detroit location showed heavier concentrations throughout the business hours and no particularly sharp peaks. This is due to the fact that at this location there was no excessive traffic in the morning and afternoon, but rather a sustained traffic flow throughout the business day. The data at the neighborhood shopping area, like that at the depressed highway, shows peaks in the morning and afternoon with higher concentrations in the afternoon. This is again due to the location of the sampler in relation to the movement of traffic. Also, it is noted at this sampling station that there is a high peak

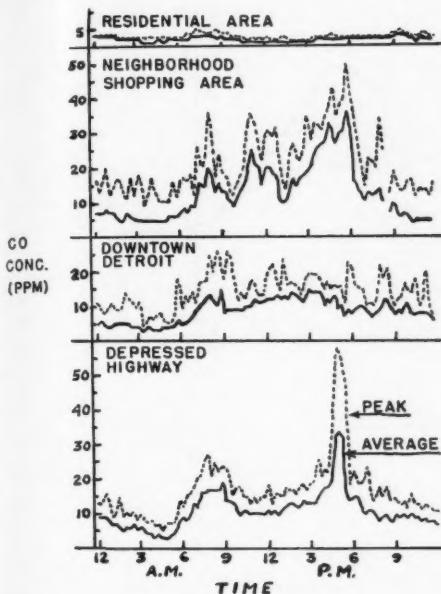


FIGURE 1. Carbon monoxide concentrations at each of four sampling sites during a typical day.

around 11:00 a.m. This surge is probably due to shoppers' traffic. The residential area data were rather uninteresting and only during a period of inversion was a substantial increase in CO concentrations noted.

For the period of 21 weeks while the recorder was operating in downtown Detroit, the CO readings at that station ranged from 0-100 ppm, with a median of 9 ppm. During the 58 week period that a machine was located in the busy

neighborhood shopping area, the data obtained showed CO readings ranging from 0-100 ppm with a median of 10 ppm. For the 27 weeks that a recorder was located on the depressed highway, the CO readings ranged from 0-100 ppm with a median of 8 ppm. The CO in the atmosphere of the residential area was sampled for a period of 18 weeks. The concentrations there ranged from 0-29 ppm with a median of only 2 ppm.

Preliminary to the more detailed statistical analysis, some suggestions regarding the hourly distribution of the variables were obtained from Figures 2 through 4.

Figures 2 and 3 describe the average hourly traffic and carbon monoxide movements at the downtown Detroit and neighborhood shopping area sample points. For the former, the average hourly wind speed and temperature readings are shown in Figure 4. The graphs show: (1) High carbon monoxide readings occur during the hours when traffic density is heavy; low concentrations are found when traffic is light. This suggests a high correlation by hour of day between carbon monoxide and traffic. (2) Average hourly percentage changes in traffic densities do not necessarily imply equivalent changes in carbon monoxide concentration. This is most noticeable during the early hours of the morning. For these hours the percentage decline in traffic is much more severe than that of carbon monoxide. This result indicates that variables other than traffic must be considered. (3) Average wind speed is relatively low during the early hours of the morning. Average temperature, though also low during these hours, does not vary greatly by hour of the day. Since it is known *a priori* that inversion is highest during the early hours of the morning, the smaller decline in carbon monoxide concentration is explained by the favorable be-

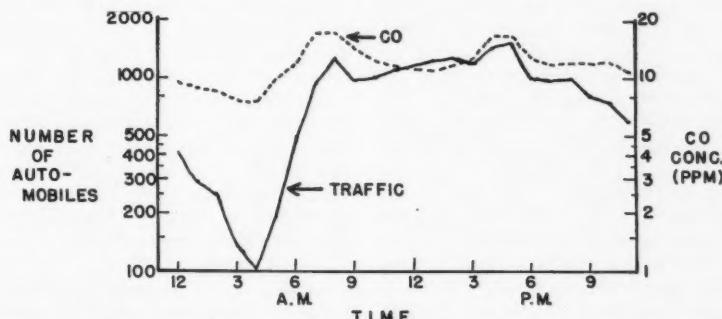


FIGURE 2. Comparison of the automobile traffic and the concentrations of carbon monoxide in the air at the downtown sampling site. The data show average values at different hours Monday through Friday one week in October, 1957.

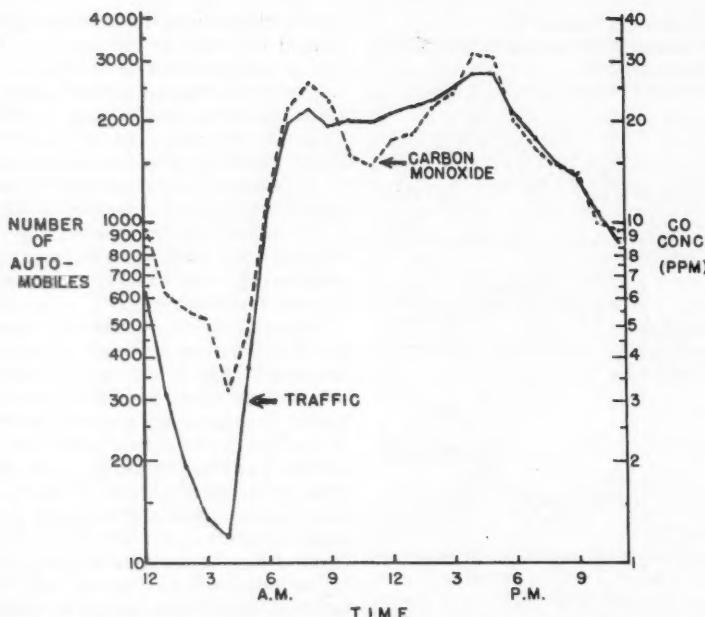


FIGURE 3. Comparison of average hourly concentrations of carbon monoxide and automobile traffic at neighborhood shopping area. Data are average daily values Monday through Friday in one week in October, 1957.

havior of the meteorological variables (retentive effect). (4) A second significant finding from Figure 4 concerns the average movements of the variables for the hours 9 a.m. to 3 p.m. Although traffic is continually increasing during this period, the carbon monoxide concentration is mainly decreasing. Again the explanation can be traced to the meteorological variables. Average wind speed and temperature readings are at their highest levels and the inversion effect is small or nonexistent (dispersive effect). (5) There does not appear to be a significant time lag between traffic and carbon monoxide at either station. The two series, for most hours of the day, move together. (6) Traffic and carbon monoxide movements are more closely correlated at the neighborhood shopping area station than at the downtown Detroit location. For the former station therefore, the regression coefficient of the traffic variable in the regression function will be larger; that is, the traffic variable at the neighborhood shopping area station will explain a larger proportion of the variation in carbon monoxide concentration in the atmosphere.

The variations of carbon monoxide concentrations in the atmosphere by day of the week

and month of the year are presented in Figure 5 and Table I.

Figure 5 shows: (1) Carbon monoxide variability is smallest during the hours of midnight-5 a.m. The relative stability of the meteorological and traffic variables for these hours explain this result. (2) Whereas a high weekday concentration was observed between 7-8 a.m. and 4-6 p.m. (traffic going to and returning from work) no similar pattern appeared for the weekend days. It may be noted that on Saturday at the neighborhood shopping area high concentrations occurred during the afternoon shopping period while the other stations did not show unusually high concentrations. All the stations except the residential area location showed lower concentrations on Sunday. The residential area location showed a slight increase in the morning hours with the exception of Sunday and Monday. This increase is probably due to temperature inversion effects.

Table I shows the median CO concentrations by month at the four sampling locations. It may be noted that at the depressed highway location the readings ranged from 7-11 ppm, at the downtown location from 7-10 ppm, at the neighborhood shopping area from 6-17 ppm,

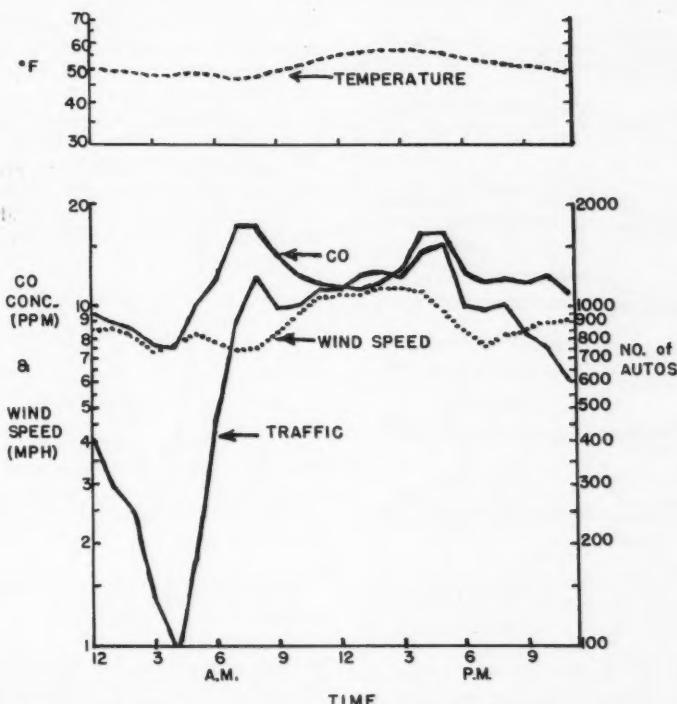


FIGURE 4. Comparison of average carbon monoxide concentration, wind speed, and temperature by hour of day.

and at the residential area location from 1-3 ppm. The results at the three business locations are surprisingly uniform. It may be noted that the concentrations increased during September and October. This is undoubtedly due to the temperature inversion which prevails in this area at that time of the year.

Figure 6 shows a comparison of average traffic conditions and average CO concentrations during periods of inversion and no inversion at the downtown Detroit sampling location. It may be noted that except for the hours 10:00 a.m. to 4:00 p.m., when inversion does not usually occur, the average hourly CO concentrations in the atmosphere are significantly higher during periods of temperature inversion. Note, however, the similarity of hourly traffic movements for the two time-series. A one way analysis of variance test of the downtown Detroit data (inversion vs. no inversion) proved to be significant.

Figure 7 shows a comparison of average traffic conditions and CO concentrations during periods of low and medium wind speed at the

downtown Detroit location. It is interesting to note that whereas the traffic movements are very similar for the two time-series, the average hourly CO concentration is always higher for the low wind speed data.

#### Mathematical Model

An important phase of this investigation was an effort to utilize the atmospheric data obtained to formulate a mathematical expression which would predict under what conditions excessively high CO concentrations could accumulate in the Detroit area and thus be instrumental in producing an air pollution disaster.

We were interested in knowing if it would be possible to determine if there should be a limit as to the number of cars traveling Detroit highways; what meteorological conditions would have to prevail to have an excessive accumulation of CO in the atmosphere and what the other sources of CO in a community contribute to pollution.

As a first approximation to the "true" relationship between the variables, there was fitted

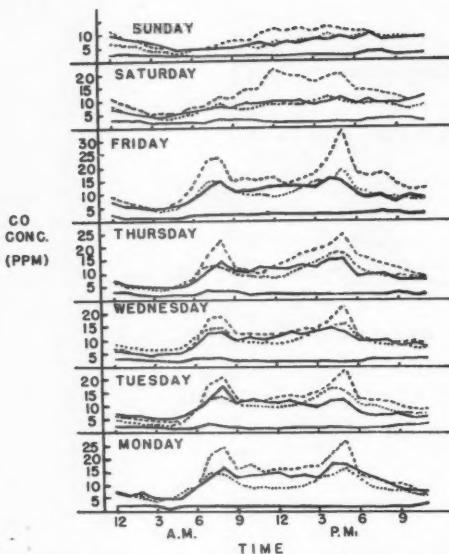


FIGURE 5. Hourly median carbon monoxide concentrations by day of week for the four sampling sites. Broken line (upper in all graphs) is for the neighborhood shopping area; dotted line is for the depressed highway; upper solid line is for the downtown area; and the lower solid line is for the residential area.

TABLE I  
Median CO Concentrations by Month at the Various Sampling Locations

Month	Depressed highway	Down-town Detroit	Neighborhood shopping area	Residential area
August, 1957	—	—	—	—
September, 1957	11 ppm	—	—	—
October, 1957	10 ppm	10 ppm	13 ppm	—
November, 1957	8 ppm	9 ppm	6 ppm	—
December, 1957	7 ppm	9 ppm	9 ppm	—
January, 1958	8 ppm	7 ppm	9 ppm	—
February, 1958	7 ppm	8 ppm	6 ppm	—
March, 1958	—	—	9.5 ppm	1 ppm
April, 1958	—	—	10.5 ppm	2 ppm
May, 1958	—	—	—	2 ppm
June, 1958	—	—	—	2 ppm
July, 1958	—	—	—	3 ppm
August, 1958	—	—	—	—
September, 1958	—	—	17 ppm	—
October, 1958	—	—	18 ppm	—
November, 1958	—	—	10.5 ppm	—

to the weekday data by classical least squares the following mathematical model. Assume for neighborhood shopping area and depressed high-

way stations that carbon monoxide ( $X_1$ ) can be expressed as a linear function of some known or fixed variables: wind speed ( $X_2$ ), temperature ( $X_3$ ), northbound traffic ( $X_4$ ), southbound traffic ( $X_5$ ), inversion ( $X_6$ ), and time of the day ( $X_7$ ), with residual errors which are normally and independently distributed with mean zero and constant variance (for downtown Detroit northbound and southbound traffic are combined and the time variable omitted).

Algebraically the model is

$$X_{1j} = B_2 X_{2j} + B_3 X_{3j} + B_4 X_{4j} + B_5 X_{5j} + B_6 X_{6j} + B_7 X_{7j} + e_j$$

where

$$j = 1, 2, \dots, n.$$

The first attempts which were made indicate that this mathematical procedure, although essential to obtain first approximations, did not give the desired results and further analyses are now in progress.

#### Relation of Occupation and Certain Other Factors to Traffic Accidents

The occupation of drivers and pedestrians involved in accidents was obtained primarily to have the information available for investigation as to the possibility of an occupational carbon monoxide exposure being the source of a high carboxyhemoglobin of an injured driver or pedestrian, rather than the carbon monoxide present in the traffic environment.

The information on traffic accidents was recorded by a group especially trained in the investigation of this type of traffic accidents, namely, the staff of the Accident Prevention Bureau (APB) of the Detroit Police Department.

These officers, who investigate some 40% of all traffic accidents in Detroit, were instructed to fill out a special report form of our design for each driver and pedestrian involved in all accidents which they investigated. Exceptions occurred where the exigencies of the emergency caused it to be infeasible to take the brief time necessary for recording the data and where the severity of the injury did not permit eliciting information on certain of the items. Extensive tables have been prepared showing accident frequency by occupation. Space does not permit presenting all these data.

Classifications established by the United States Department of Commerce, Bureau of Census, in their *Bulletin P-C22, 1950 U. S. Census of Population* were used to designate occupational

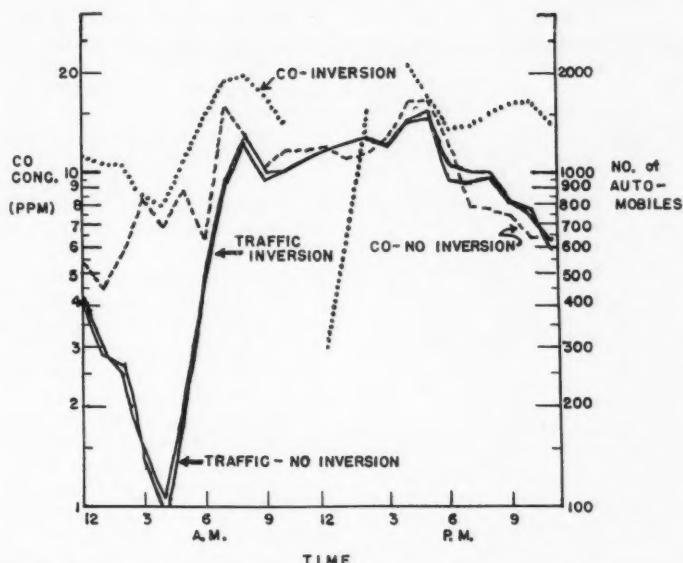


FIGURE 6. Comparison of average traffic conditions and carbon monoxide concentrations during periods of inversion and no inversion.

groups. For the various classification groups, the percentage of accidents attributed to each group was found in comparison to the percentage of the population represented by that group to be:

Professional, technical, etc.	slightly higher
Managers, officials, proprietors	slightly lower
Clerical, etc.	appreciably lower
Farmers, farm laborers, and farm managers	appreciably lower
Laborers	decidedly higher
Operators, etc.	lower
Craftsmen, foremen, etc.	higher
Service workers, salesmen, private householders	lower

The data are based on 4,052 consecutive accident reports prepared specifically for our purposes and includes 4,996 persons involved in these accidents occurring over the period February 7 to April 30, 1957. Those occupations where high CO exposures would be expected did not have, with few exceptions, high accident rates. It was concluded that occupational CO exposures did not influence driving ability.

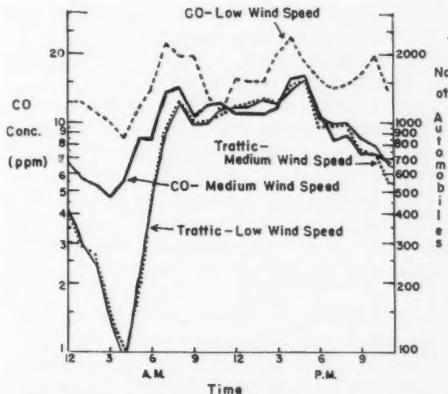


FIGURE 7. Comparison of average traffic conditions and carbon monoxide concentrations during periods of low and medium wind speed.

#### Relationship of Atmospheric CO Inside a Car to Percent CO Hemoglobin

An attempt was made to correlate per cent carbon monoxide in the blood to carbon monoxide concentrations in air. The work involved travel in a police scout car for about 8 hours over a distance of 130 miles. Data on the concentration of CO in the air in the car was

TABLE II  
Frequency Distribution of CO  
Blood Analyses

Blood saturation in per cent of CO-hemoglobin	Total number of anal- yses	Status of individuals involved			
		Drivers	Pedes- trians	Passen- gers	Un- knowns
Less than 1.0	73	27	30	5	11
1.0-1.9	45	21	17	1	6
2.0-2.9	30	14	11	1	4
3.0-3.9	14	6	6	—	2
4.0-4.9	25	12	6	3	4
5.0-5.9	14	6	7	—	1
6.0-6.9	10	3	4	1	2
7.0-7.9	7	5	2	—	—
8.0-8.9	4	3	1	—	—
9.0-9.9	2	2	—	—	—
10.0-10.9	1	—	—	—	1
11.0-11.9	1	1	—	—	—
31.5	1	—	—	—	1
Clotted	7	2	3	1	1
Broken	3	1	2	—	—
Totals	237	103	89	12	33

monitored continuously with an MSA carbon monoxide detector, and intermittently with NBS carbon monoxide indicator tubes. Readings of the CO concentration were taken and recorded at five minute intervals. Carbon monoxide levels in blood were recorded at two hour intervals. Included was one participant who smoked cigars and another who was a non-smoker. There was a continuous flow of air into the vehicle so that CO in the air reflected outside traffic conditions at all times, and was not influenced by any tobacco smoke within the vehicle.

Fifty readings taken with the MSA detector showed an average CO value of 17 ppm. The peak value of 120 ppm was attained when the vehicle was not moving, but the engine was idling.

Nine CO blood values were determined. A slight rise in the CO content of the blood was evidenced: 0.8 to 1.2 per cent CO-hemoglobin for the non-smoker, and 3.1 to 3.9 per cent CO-hemoglobin for the smoker. The smoking rate for the latter was essentially the same throughout the sampling day.

#### Carbon Monoxide in Blood Values for Accident Victims

Arrangements were made with the city of Detroit, Department of Health, Receiving Hospital

to obtain a blood sample from the drivers of automobiles and pedestrians involved in accidents and brought to the hospital for treatment. A case history was prepared for each sample received, whenever possible. This case history contained such information as: name, driver or pedestrian, were glasses worn, accident occurred on way from job, occupation, number of hours driving prior to accident, degree of smoking, traffic conditions, general condition of vehicle, condition of exhaust pipe and muffler, location of accident, date, day of week, time of day, vehicle make and year, location of air inlet, whether person had been drinking, was their ability to drive impaired, time blood sample was taken, date analyses were performed, and results of blood analyses.

Table II presents the blood saturation in percentage of CO-hemoglobin. Of the 237 samples analyzed, 50% were below 2.0 per cent saturation. A comparison of the drivers' percentage of saturation to the pedestrians' percentage of saturation shows that 50% of the drivers had less than 3.0% saturation, whereas 50% of the pedestrians had less than 2.0% saturation. The last column shown as "unknowns" refers to those samples where it was not possible to obtain information as to whether the person involved was a driver or a pedestrian.

A comparison of the number of drivers to the number of pedestrians in the various percentage classifications show a slightly higher number of drivers with the higher percentage saturation than pedestrians, however the numbers are not sufficiently large to warrant any conclusion.

Although more work needs to be done on the carboxy hemoglobin saturation required to affect sensory-motor performance, the opinion is generally held, and the authors concur, that any CO-hemoglobin saturation less than 10% will not cause any disturbance in driving ability. Considering that only three persons out of the 237 were in excess of this figure, it must be concluded that the CO concentrations in the general atmosphere of an urban area such as Detroit is not a factor in impairing driving ability.

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2. AAGE GRUT, *Chronic CO Poisoning*, (Copenhagen: Ejner Munksgard, 1949) (includes 180 references)

# Protective Clothing Program at the Savannah River Plant\*

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## Introduction

IN THE rapidly expanding atomic energy industry, protective clothing is frequently worn to prevent contamination of the body with radioactive materials and to exercise contamination control. The cost of this protection, while small compared with other operating costs, nevertheless, requires a substantial yearly expenditure. At large atomic energy facilities such as the Savannah River Plant, protective clothing costs are sufficient to justify a continuous evaluation program in order to protect this investment and to insure that maximum protection is provided for employees. The major responsibility for providing this continuous evaluation program is assigned to the Health Physics Section; however, it necessarily requires the cooperation of the purchasing agent, the storeroom facilities, the laundry as well as the users themselves.

## Methods of Approach

Two approaches have proven successful in showing direction for the evaluation program. First, a review of past experience regarding body contamination provides some measure of the effectiveness of clothing in protecting personnel. Such a review will often indicate flaws or inadequacies; however, other factors such as improper wearing of clothing are reflected and must also be considered.

The second approach is concerned primarily with economic aspects and consists of making continuous reviews of clothing cost data. An investigation of clothing requiring the largest expenditure for replacement is a logical starting place in reducing costs. Although both approaches are followed simultaneously, the latter has received the major effort since existing clothing has been, in most cases, more than adequate.

## Projects Initiated to Insure Adequate Protection

Several investigations were initiated to insure that maximum protection is provided. One in-

vestigation resulted from a review of personal clothing and skin contamination during an extended maintenance program which required close contact work with grossly contaminated equipment. Although skin contamination incidents occur infrequently under normal conditions, a significant increase was noted during this work. A preliminary investigation revealed that most incidents resulted from the penetration of contaminated particulate matter through the fabric of the coverall.

A further investigation was begun to determine whether the fabric in use provides optimum protection. A cotton mill was visited to discuss imperviousness of fabrics, to review standard testing methods and to obtain fabric samples. The selected basis for comparison was a measurement of the air flow rate through a specific cross-sectional area at a constant pressure drop of desired sample swatches. This is a standard mill test used to determine the porosity of fabrics. Data obtained from several samples are shown in Table I.

As a result of these studies, a new fabric (7.8-ounce drill with 72/60 thread count) was chosen. Coveralls made of this fabric provide twice the protection against penetration of particulate matter. In addition, the lighter weight gives added comfort in a southern climate, the drill weave is more durable, and the cost is less than the previously used herringbone twill fabric.

An additional investigation was prompted not as the result of previous experience but because foresight indicated data were needed to provide a guide in specifying garments for protection against tritium oxide. This contaminant results from neutron capture in deuterium oxide and may become a problem wherever heavy water is used as a reactor moderator. Because little data were available in the literature on this subject, studies were carried out to determine which rubber and plastic materials are least permeable and provide optimum protection.

Since tritiated heavy water has many physical properties similar to water, tests were first conducted to measure the rate of water vapor permeation through a variety of plastic and rub-

\* Presented at the Twentieth Annual Meeting of the American Industrial Hygiene Association, Chicago, Illinois, April 30, 1959.

TABLE I.  
Air Flow Porosity Measurements

Fabric weight, ounces/sq yard	Thread count†	Type weave	Air flow, cfm
7.6	115/56	Twill	49
7.8*	72/60	Drill	22
8.0**	96/56	Twill	44
8.2	74/60	Drill	17
8.5	113/58	Twill	24
8.7	112/56	Twill	20

\* Fabric adopted.

\*\* Herringbone twill fabric in use prior to above tests.

† Thread count = warp threads per inch/fill threads per inch.

TABLE II.  
Water Vapor Permeability Tests

Material	Thickness, mils	Avg. permeability constant, cc/sec/ cm <sup>2</sup> /cm thickness/ cm Hg pressure
Plastics		
Saran	1.5	0.07 × 10 <sup>-7</sup>
"Mylar"	0.5	0.2 × 10 <sup>-7</sup>
Polyvinyl Chloride	6	2.2 × 10 <sup>-7</sup>
Polyethylene	1.5	0.2 × 10 <sup>-7</sup>
Aluminized "Mylar"	2.0	<0.01 × 10 <sup>-7</sup>
Rubber		
Natural latex	18	3.8 × 10 <sup>-7</sup>
Neoprene	24	2.0 × 10 <sup>-7</sup>
Butyl	32	1 × 10 <sup>-7</sup>
Miscellaneous		
Rubber acid-suit fabric	20	11 × 10 <sup>-7</sup>
Neoprene-coated nylon	14	8.8 × 10 <sup>-7</sup>
Neoprene-nylon laminate	34	2.7 × 10 <sup>-7</sup>

ber materials. Permeability constants, which are independent of thickness and provide a fundamental constant for each type material, were determined using standard Payne Permeability Cups. Later, separate tests using tritiated heavy water rather than ordinary water showed similar results and helped confirm the validity of the studies. Data showing the permeability constants measured for many of the materials tested are shown in Table II. This investigation has provided data from which an intelligent selection and specification can be made for garments worn as protection against tritium oxide.

#### Projects Initiated to Reduce Costs

Perhaps the most fruitful phase of the continuous evaluation program has been the substantial decrease in protective clothing costs which was achieved without sacrificing the protective value of the garments. During an earlier review of cost data it was found that coveralls required the largest replacement expenditure. On this basis, an investigation was launched to

determine what measures could be taken to reduce these costs. The following measures were adopted:

(1) Use of unbleached garments and elimination of unnecessary pockets.

(2) Use of outer "throw-away" coveralls.

Two pairs are required where large amounts of radioactive contamination may be encountered. Frequently, the outer pair of coveralls becomes contaminated to a level which exceeds the normal laundry limit and must be discarded directly as waste.

Although efforts to locate a commercially available garment which could be economically discarded after one use have been unsuccessful, a survey revealed that 90% of the laundered coveralls which are rejected for reuse due to excessive residual contamination are contaminated to within 1 to 3 mrad/hr. Since the residual contamination becomes fixed in the garment through laundering, coveralls within this range are now being saved, appropriately marked, and used as outer disposable garments.

After coverall costs had been reduced appreciably, another survey of cost data showed that surgeons gloves had become the item requiring the largest yearly expenditure. Previous attempts to launder surgeons gloves in the commercial laundering equipment were unsuccessful because they conglomerated. It became standard practice to discard them after each use.

After considerable searching, which included visits to several local hospitals where gloves are normally recovered, it was found that these gloves could be laundered successfully and economically with special treatment. A home-type washer-dryer machine was purchased and used to develop a special decontamination wash and drying cycle which includes pretalcing. Surgeons gloves are now routinely processed in this equipment, monitored on both sides and returned for only one-quarter the cost of replacement.

A later review of cost data showed that wrist-length rubber gloves were responsible for a large yearly expenditure. Although an investigation revealed little could be done to reduce usage, it was found that existing specifications required purchase of the gloves from a specified manufacturer. After contacting other manufacturers, many samples were obtained, tested and evaluated to determine their acceptability as substitutes. Gloves from two other manufacturers were found to be acceptable and considered as equals. By establishing competitive bidding, glove costs were reduced by 20%.

Cost data can also be utilized to indicate trends and thus prevent garments from reaching



FIGURE 1. One-piece polyvinyl suit originally used (thickness, 12 mils).

the top of the expenditure list. For example, air-supplied one-piece plastic suits (as shown in Figure 1) were being used for maximum personal

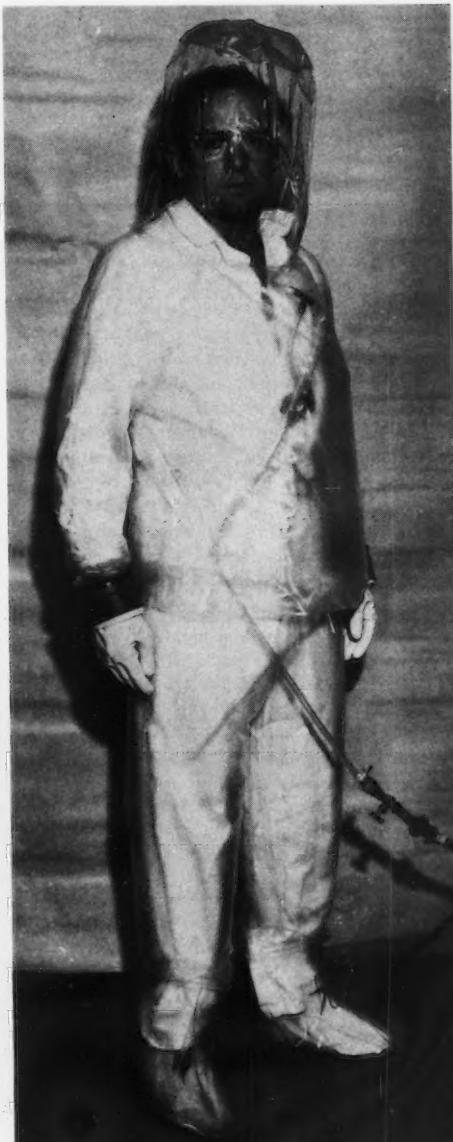


FIGURE 2. Two-piece polyvinyl suit (thickness, 6 mils) now replaces the one-piece suit at one-seventh the cost.

protection during some phases of work in highly contaminated areas. Over a period of several years their use continued to increase. By contacting and assisting the manufacturer, a two-

piece suit was developed (as shown in Figure 2) which provides adequate protection and greater comfort at only one-seventh the cost of the original suit.

#### Miscellaneous Projects

Some improvements in the protective clothing program were brought about by suggestions from the users themselves. For example, several comments were received that it was difficult to attach the necessary film badge and pocket chamber dosimeters on coveralls and laboratory coats. A simple change in purchase specifications, which required a four-inch strap to be located on the left chest area, has eliminated the problem. Other comments indicated laundry shrinkage caused most cotton garments (gloves, shoe covers, caps, coveralls and laboratory coats) to become uncomfortably tight after several launderings. By changing specifications to require purchase of extra large garments, thereby allowing for shrinkage, this problem was solved.

These projects represent only a portion of those which have resulted from the continuous

evaluation program. There are many projects yet in the future, such as:

(1) Reclamation of leather gloves.

A recent review of cost data showed a major expenditure was for leather gloves. At present, leather gloves are being collected for delivery to an AEC-approved commercial decontamination laundry to evaluate the results of dry cleaning and reclamation. If successful, the estimated cost of decontamination and recovery would be only one-fifth the cost of replacement.

(2) Evaluation of newly developed and marketed products.

#### Conclusions

Although protective clothing costs at large atomic energy installations justify maintaining a continuous evaluation program, a similar evaluation conducted on a six-month or yearly basis may be justified by smaller facilities. The over-all results of our continuous evaluation program have been an increase in the protective value of garments and a savings which exceeds \$300,000 per year.

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#### NEW RADIOACTIVITY STANDARDS

THE NATIONAL BUREAU OF STANDARDS has announced the availability of several new standard solutions for radioactivity measurements. A new series of radium standards have been prepared to restock the nearly depleted and less accurate 1940 supply with activities between  $10^{-6}$  g and  $10^{-11}$  g values. New "blank solutions," containing  $0.02 \times 10^{-12}$  g of radium, are available for dilution purposes.

Three new gamma-ray radioactivity standards, consisting of strontium-85, niobium-95, or mercury-203 in about five grams of solution, can now be obtained in sealed glass ampoules. As of August 15, 1959 the strontium-85 sample had a total nominal activity of  $2 \times 10^6$  disintegrations per second; niobium-95 had  $6 \times 10^8$  d/sec; and mercury-203 had  $10^7$  d/sec. These three samples can be issued only under the special licensing provisions of AEC.

# Nuclear Safety in Manufacturing Plants\*

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## Introduction

OVER recent years, a sizable and increasing fraction of reactor fuel fabrications has been carried out in industrial plants not associated with the large Atomic Energy Commission installations. These plants operate either under government contract or the AEC licensing program. Fabrications performed under contract remain under AEC control and are obligated to conform to health and safety provisions which are specified in the particular contract. To obtain a license to fabricate fuel, one must first apply to the AEC, demonstrating a capacity for assuming the responsibility of handling the fissionable material, as well as that adequate health and safety measures can be and will be incorporated into the process. In both cases, health and safety provisions are needed to assure that unwanted criticality does not occur. This criticality control is called nuclear safety.

In general, the assurance of nuclear safety is a three-step problem.<sup>1</sup> First, there are the scientific considerations having to do with the measurement of basic nuclear properties, the subsequent calculation of critical parameters, and a comparison of these parameters with the results of critical experiments. The next step involves engineering, wherein one determines that the contemplated disposition and configuration of fissionable material in the design of a fabrication or process conforms to nuclearly safe values. This safety of design must not be alterable by off-standard conditions, such as human or equipment failure. The third step in assuring nuclear safety is administrative in nature in that controls must be set up or modified to offset possible equipment and personnel failure. Oftentimes this step also involves an independent check of the proposed process, for example, in examining a proposed contract or license application. However, the nuclear energy business has expanded so rapidly that there are not enough persons available to resolve adequately the numerous nuclear safety problems. This is especially true in the case of small plant or commercial-type fabrications, when the serv-

ices of a full-time criticality engineer cannot be justified. Hence, the independent analysis can become very important.

The conditions sought in nuclear safety are quite opposite to those desired in nuclear reactor design. In the latter case, good neutron economy is essential, while when striving for nuclear safety the absorption of neutrons in nonfissionable materials and neutron leakage ought to be as high as reasonable. In the following pages are summarized the factors which influence neutron economy and which, therefore, are important in nuclear safety.

## Shape

A shape having a low ratio of surface area to volume is optimal in reducing neutron leakage. Spheres, as well as near spherical shapes such as cubes or cylinders having equal diameters and heights, are the most reactive. Hence, arranging fissionable material as thin cylinders or slabs is desirable in assuring nuclear safety. This can be illustrated by referring to a parameter called buckling or  $B^2$ .

The description and derivation of  $B^2$ , which appears in many technical reports and books, is beyond the scope of this discussion. In particular, the reader is referred to the textbook, *The Elements of Nuclear Reactor Theory*<sup>2</sup> by S. Glasstone and M. Edlund. Briefly, the buckling is a measure of the curvature or "buckling" of the neutron flux as a function of position in a reactor core. The critical equation of a reactor system relates  $B^2$  with the physical characteristics affecting neutron multiplication and diffusion of the materials combined to form the system.  $B^2$  is actually a geometric quantity, its value depending upon the shape and size of the reactor. Hence, a reactor is critical when its shape and size results in a value for  $B^2$  which is equivalent to that  $B^2$  value inferred from the materials in the system.

Values of  $B^2$  for some common shapes and the corresponding minimum critical volumes as reported by Glasstone and Edlund are shown in Table I. The letters in the Table refer simply to the dimensions of the shape in question. It should be noted that  $B$  has no specific label, though its value is calculable from the system's dimensions.

\* Presented at the Twentieth Annual Meeting of the American Industrial Hygiene Association, Chicago, Illinois on April 30, 1959.

TABLE I  
Dimensions and Bucklings for Some  
Common Shapes

Geometry	Bucklings	Min- imum critical volume
Infinite slab	$\left(\frac{\pi}{a}\right)^2$	—
Rectangular parallelepiped	$\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 + \left(\frac{\pi}{c}\right)^2$	$\frac{161}{B^3}$
Cylinder	$\left(\frac{2.405}{R}\right)^2 + \left(\frac{\pi}{H}\right)^2$	$\frac{148}{B^3}$
Sphere	$\left(\frac{\pi}{R}\right)^2$	$\frac{130}{B^3}$

*a* = thickness

*b* = width

*c* = length

*R* = radius

*H* = height

The data in Table I indicate that a spherical shape has the smallest minimum critical volume. Since neutron production in a critical system occurs throughout the volume and leakage depends on surface area, it is clear that a sphere will be most reactive for a given composition and such shapes should be avoided.

### Moderation

Cross sections for neutron captures which lead to fission increase greatly as the neutron energies decrease to the thermal range. This neutron thermalization takes place when fissionable atoms are mixed with certain materials called moderators. The most common moderating material found in a processing plant is ordinary water. The effect of neutron moderation is to decrease greatly the minimum critical mass for metallic U-235, about 22.8 kilograms, to one of about 0.8 kg for a homogeneously mixed U-235 water system. Both of these values refer to the fully water-reflected situations. Figure 1 is a curve obtained from an Oak Ridge report, *Studies in Nuclear Safety*,<sup>2</sup> which illustrates the variation of the critical masses of U-235 as highly enriched uranium with the size of metallic pieces in water lattices. The uranium solution is the most reactive uranium system having a minimum critical mass of less than 1 kg of U-235. Critical mass increases with the metal size till a value of 22.8 kg of U-235 is necessary for the reflected solid, metal sphere. Each of the intermediate points represents an optimum lattice, that is, one with a minimum mass.

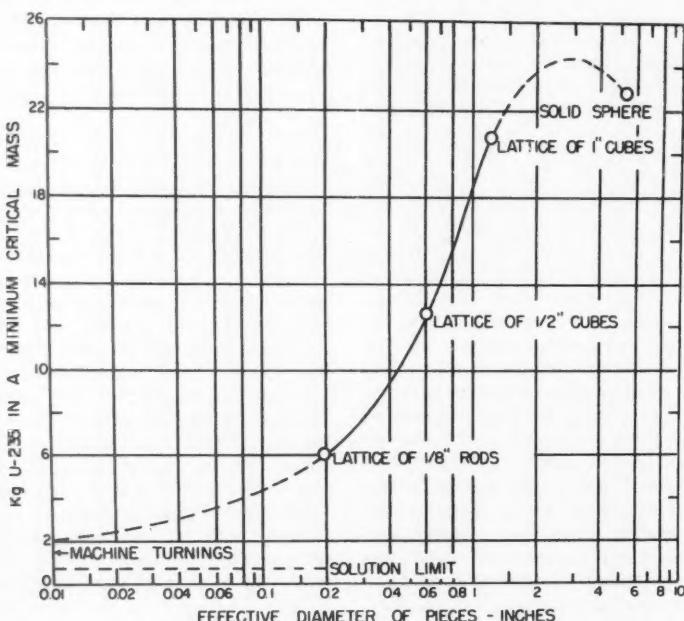


FIGURE 1. Effect of dispersing solid pieces of uranium (U-235 enrichment 93.2%) metal in water.

### Reflection

Surrounding fissionable material with almost any material will increase the system's reactivity by reducing neutron leakage. Just as the mixing of a moderator with fissionable material often increases reactivity; *i.e.*, results in a lower mass requirement for criticality, so the addition of a neutron reflector has a similar effect. In evaluating the safety of processes, it is customary to assume more severe operating conditions than one would normally expect. Hence, most processes are designed to be safe even in the unlikely event of flooding with water. Of course, flooding of a process area is possible, because of a water main or sprinkler system failure. A more important reason for the flooding assumption, however, is to account for the unknown neutron reflecting properties of incidental materials such as equipment, walls, and personnel. If a single unit or system containing fissionable material is subcritical or safe under flooding conditions, it would be safe during reasonably foreseeable abnormal conditions. Removing the reflector from between neighboring units, however, can increase the reactivity of an array by neutron interaction. The interaction problem is discussed later. Two examples to illustrate the effect of a reflector are noteworthy. First, Table II illustrates how the addition of a thick water reflector affects the critical mass ( $M_c$ ) of metal spheres of U-235 and Pu. An unreflected sphere of highly enriched uranium has a critical mass of about 48 kg of U-235 which is reduced to 22.8 kg, the value mentioned earlier.<sup>3</sup> Plutonium experiences a similar factor of two reduction in critical mass. The second example, which was inferred from some early Oak Ridge work with uranyl fluoride solutions by Beck, Calahan and others,<sup>4</sup> is shown in Figure 2. The reactivity increase by neutron reflection is illustrated clearly here. For a 10-inch diameter aluminum-contained, homogeneous reactor, water reflection reduces the required critical U-235 mass by about 58% of the mass needed for a bare cylinder. The reduction achieved by adding a reflector for the stainless steel case is only about 51%. The curves indicate that in both cases adding reflectors becomes somewhat less important as diameter increases. This is explained by the fact that, for a given concentration of U-235, a large fraction of the neutrons escape a smaller diameter reactor and are available for reflection. As the reactor size increases, therefore, the critical masses with and without a reflector become more comparable.

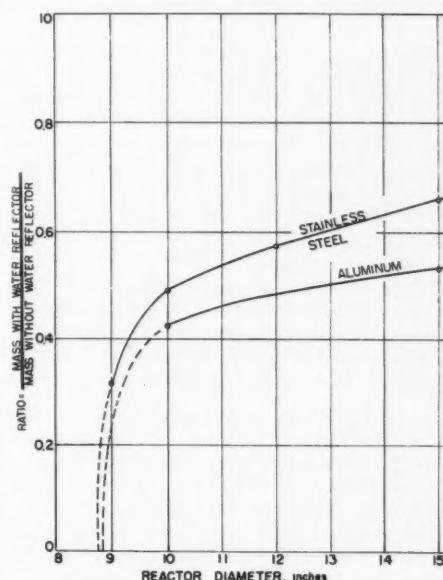
### Concentration

The U-235 concentration in solution also has an important effect in criticality. In the previous

TABLE II  
Comparison of Critical Masses of Plutonium and U-235 Metal Spheres

Reflector	$M_c$ (Pu) (kg)	$M_c$ (U-235) (kg)
None	16.2	48.0
Water	8.0	22.8

(Pu density 15.8 gm/cc, U-235 density 18.8 gm/cc)



NOTE:  
HU-235 ATOMIC RATIO=100 FOR  
VARIOUS REACTOR DIAMETERS

FIGURE 2. Effect of water reflection on aluminum and stainless steel contained reactors.

curve (Figure 1), the reduction of critical mass with decreasing size of the highly enriched uranium metal units was shown. Hence, homogeneous or solution data can often be used to assure the nuclear safety of heterogeneous enriched systems. However, the variation of U-235 concentration in solutions also changes the criticality parameters significantly. This variation is attributable to fast neutron leakage and multiplication factor,  $k$ , which are competing effects. A fairly simple computation can illustrate this variation. First, the infinite multiplication factor, for a highly enriched uranium system, is

$$k_{\infty} = \eta f = \frac{\eta}{1 + \left( \frac{H}{U-235} \right) \left( \frac{\sigma_U}{\sigma_H} \right)} \quad (1)$$

TABLE III  
Distribution of Neutron Absorption in Enriched Uranium Solutions

Absorber	H:U-235 = 25	H:U-235 = 1000
U-235 fission	84.1%	57.0%
U-235 radiative capture	14.1	9.5
Hydrogen	1.2	33.3
Impurities	0.4	0.2

where  $\eta$  is the average number of fission neutrons per thermal neutron capture produced in the uranium and  $f$  is the ratio of the thermal neutrons absorbed in the fuel to the total number absorbed. The  $\sigma$ 's are the microscopic absorption cross sections for the hydrogen of the water and the uranium. The oxygen in water can usually be neglected. H:U-235 is the ratio of hydrogen atoms to U-235 atoms. Obviously, as H:U-235 increases,  $k_\infty$  decreases slowly.

Now the systems of practical interest are finite in size and account must be taken of neutron leakage. This can be done by considering the modified two neutron energy group treatment employed by J. A. Pond,<sup>5</sup> namely

$$k_{\text{eff}} = \eta f U_t U_f, \quad (2)$$

where  $U_t$  and  $U_f$  are the thermal and fission neutron nonleakage probabilities, respectively, and  $k_{\text{eff}}$  is the effective neutron multiplication factor of the system in question; *i.e.*, it is  $k_\infty$  multiplied by the fraction of neutrons which do not escape or leak out. For a critical reactor,  $k_{\text{eff}} = 1$ , and the above equation can be rearranged to

$$\frac{H}{U-235} = \frac{\sigma_U}{\sigma_H} (\eta U_f U_t - 1). \quad (3)$$

To maintain criticality while varying the H:U-235 ratio, obviously the nonleakage probabilities must be changed also. As indicated earlier, increasing H:U-235 at first improves neutron thermalization by the hydrogen atoms and neutron leakage decreases. Hence, a smaller critical mass is needed as H:U-235 increases through low ratio values. At some point, thermalization becomes relatively constant and the required critical mass reaches a minimum. At high H:U-235 ratios, neutron absorption by hydrogen becomes important and the critical mass increases. A further effect is noteworthy, namely that the increasing H:U-235 ratio or greater dispersion of atoms further increases the critical mass and, hence, the reactor volume increases very rapidly.

There exists an H:U-235 atom ratio above

which criticality is impossible. Recall that

$$k_\infty = 1 = \frac{\eta}{1 + \left( \frac{H}{U-235} \right) \left( \frac{\sigma_H}{\sigma_U} \right)} \quad (4)$$

for criticality in an infinite system. Since  $\eta = 2.08$  and  $\sigma_H/\sigma_U = 0.00048$ ,

$$1 + 0.00048 \left( \frac{H}{U-235} \right) = 2.08$$

$$\therefore \frac{H}{U-235} \doteq 2250. \quad (5)$$

Hence, uranium solutions having atom ratios above this value, or containing less than about 11.6 gm U-235 per liter, cannot become critical.

The effect of the H:U-235 atom ratio can be illustrated further by referring to some data given by Beck in the work mentioned earlier.<sup>6</sup> Table III shows the distribution of neutron absorptions for two extreme concentrations. It should be noted that the fraction of absorptions resulting in fissions decreases markedly with increasing H:U-235 or decreasing uranium concentration. Further, the fraction of absorptions by the hydrogen in the water increases by a very large factor with decreasing concentration. To summarize, then, Figure 3 illustrates how minimum critical mass varies with H:U-235 ratio for an aluminum-contained reactor. The curves are the envelopes of experimental curves for reactors of several diameters and hence relate values for the most reactive cylinders for both reflected and unreflected aluminum and stainless steel contained reactors. Up to H:U-235 ratios of about 200, the 10-inch diameter cylinder was critical with the smallest critical mass when not reflected. At higher ratios, 15-inch diameter cylinders were more reactive. For reflected aluminum reactors, the minimum critical masses occur in smaller diameter cylinders than in the unreflected case at most H:U-235 ratios. This can be explained by the fact that neutron leakage decreases with increasing reactor size and reflectors become less important in large reactors. The minimum critical mass for all the solutions indicated is about one kg of U-235 at an H:U-235 of about 400.

For comparison's sake, note that the critical masses at H:U-235 equals 100 are 5 kg of U-235 in an unreflected cylindrical solution and only about 1.8 kg for the same solution, reflected. It should be noted further that the minimum mass occurs in an 8-inch diameter cylinder for the reflected case, but in a 10-inch diameter cylinder for the bare case. Now Figure 4 shows

CRITICAL ALUMINUM REACTORS

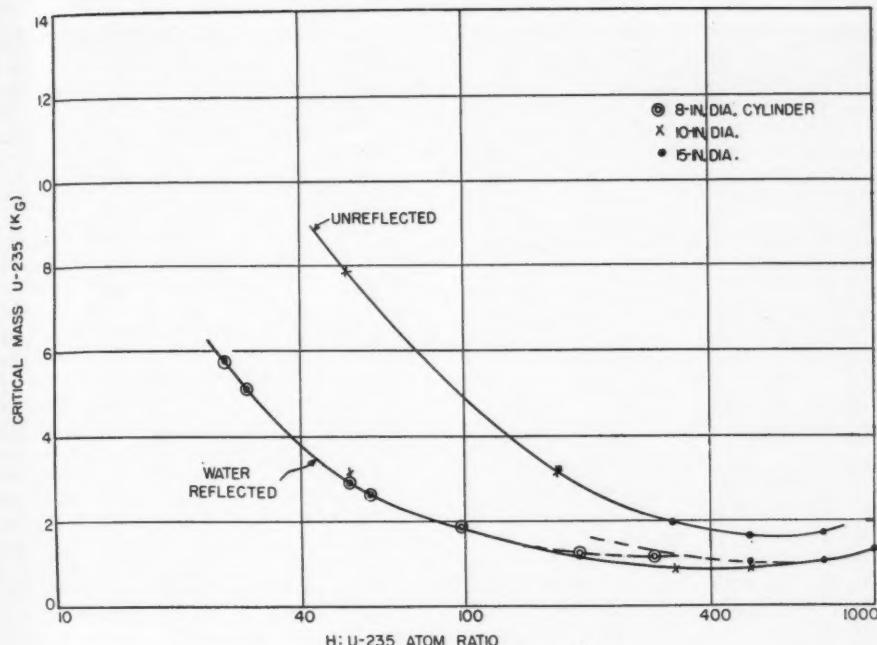


FIGURE 3. Critical aluminum reactors.

CRITICAL STAINLESS STEEL REACTORS

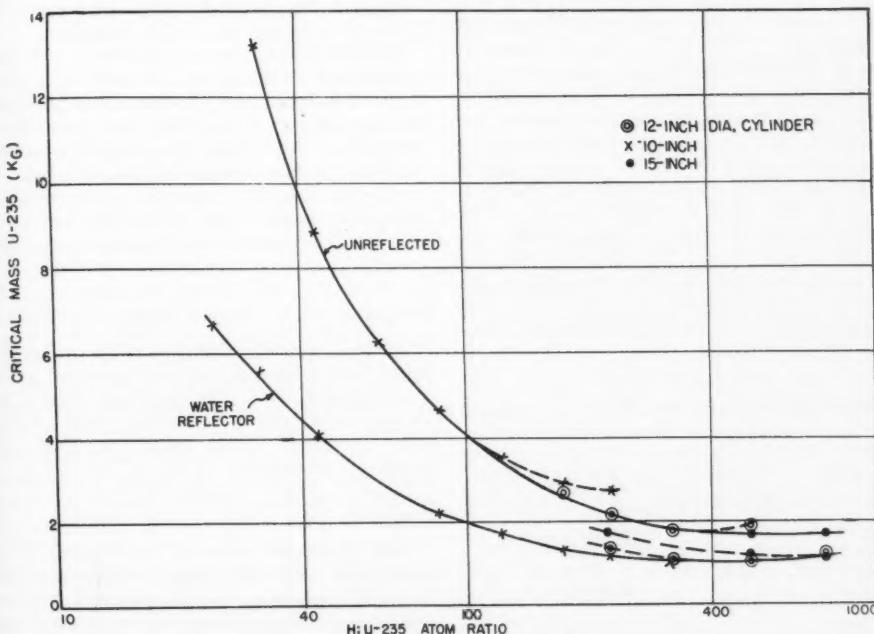


FIGURE 4. Critical stainless steel reactors.

similar curves for stainless steel cylinders. Here, the critical mass for the unreflected solution of H:U-235 equals 100 is only about 4 kg of U-235 versus 5 kg for the unreflected aluminum case. Obviously, then, the container of a fissionable material can influence criticality greatly. Adding full, water reflection, however, results in a critical mass of about 2 kg, a value only slightly higher than the same reactor in aluminum. In the one unreflected case, stainless steel is an important reflector compared to aluminum. Adding a water reflector around the steel enhances the neutron poison effect of the steel, accounting for the slight difference in the reflected cases. Hence, it is important to account for neutron reflection when verifying the safety of a process.

#### Neutron Poisons

Reference was made to the poison effect of stainless steel in comparing the reflected aluminum and stainless steel critical reactors. In general, the use of neutron absorbers to assure that a system or process is nuclear safe is undesirable. To predict the behavior of neutron poisons easily, the poison should be intimately mixed with the fissionable material and it must always remain there. Except in certain cases, neutron poisons are not mixed in reactor fuels. When they are intermixed, the proportions must be precisely determined. To use poisons in heterogeneous systems is also undesirable. For example, wrapping an unreflected vessel with a poison can actually increase reactivity, as was seen in comparing Figure 3 with Figure 4. It should be realized that one cannot identify a poison material, for example cadmium metal, simply by looking at it and, therefore, the poison ought to be at least permanently fixed in the system in question. Further, it is notable that the effectiveness of any neutron absorber varies with neutron energy. Even if a poison is effective, say during complete flooding when any fission neutrons would become pretty well thermalized, it might not be as effective under partial flood-

ing when neutron thermalization could be incomplete and large numbers of fairly energetic neutrons exist. To summarize, then, each proposed process should be examined on its own merits. However, the usual rule is not to employ neutron poisons to achieve nuclear safety, but rather additional safety.

#### Heterogeneity

Earlier, it was mentioned that the use of homogeneous or solution data for highly enriched uranium can be used conservatively to assure nuclear safety of such heterogeneous systems. Lately, however, much of the processing has involved slightly enriched uranium, in the 1-5 w/o of U-235 range. With slightly enriched uranium, a heterogeneous lattice can form a more reactive system than one which has the fuel in solution. The increasing fraction of the U-238 isotope with decreasing enrichment accounts for increased reactivity of a lumped system over a homogeneous one. The probability that neutrons being thermalized will be captured at intermediate energies increases with the amount of U-238 present in the system; *i.e.*, intermediate captures increase in systems having low enrichments of uranium. Lumping the uranium to form a heterogeneous lattice decreases the chance for such parasitic captures. A second effect is the possible increase of fast neutron fissions with increasing uranium lump size and U-238 content.

To illustrate the enhanced reactivity of heterogeneous over homogeneous systems of slightly enriched uranium, we refer to some experiments and calculations, done principally by Ketzlach at Hanford.<sup>6, 7, 8, 9</sup> Table IV compares estimated minimum critical masses of some systems of interest. It should be noted that as the degree of enrichment increases the critical masses for the two classes of systems seem to converge, as expected.

#### Density

In many processes, metallic uranium is handled in the form of an alloy with nonfissionable metal. This disperses the U-235 atoms and reduces the chance that a neutron will interact with a U-235 atom. Advantage of the reduced reactivity can sometimes be taken.

#### Interaction

Once individual units are determined to be sufficiently subcritical under foreseeable off-standard conditions, the possibility of neutron interaction among units must be considered. Obviously, subcritical units must be separated ade-

TABLE IV  
Estimated Minimum Critical Masses for Uranium  
of Various Low Enrichments

w/o U-235	Homogeneous (kg U)	Heterogeneous (kg U)
1.5	194 <sup>a</sup>	800 <sup>a</sup> (not minimum)
1.6	—	265 <sup>a</sup>
3.0	228 <sup>a</sup>	79 <sup>a</sup>
		92.5 <sup>a</sup> (in UO <sub>2</sub> )
4.9	39	—
5.0	—	37 <sup>a</sup>

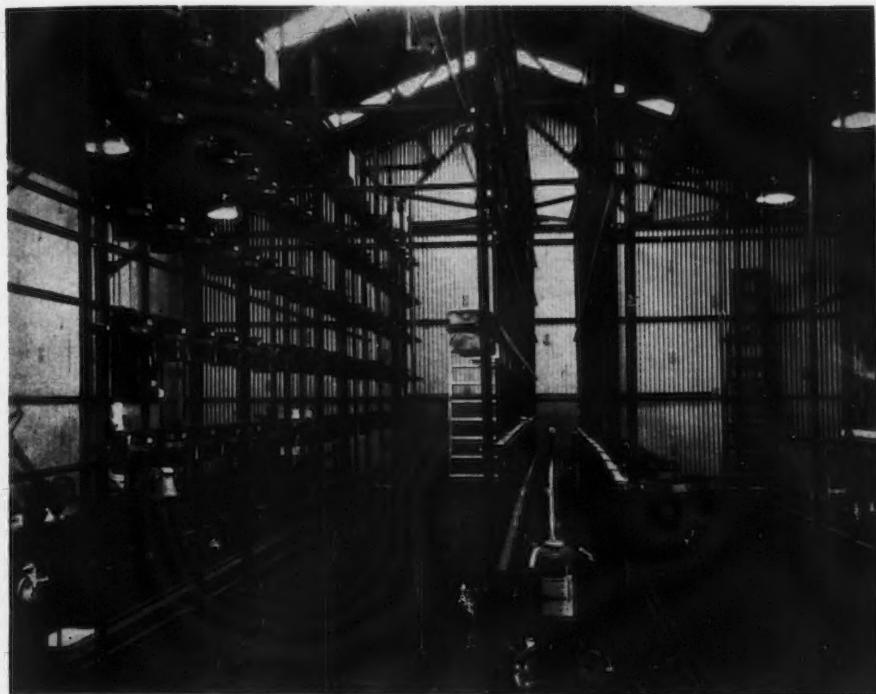


FIGURE 5. Storage array of enriched uranium chip pails. (Courtesy Nuclear Metals, Inc.)

quately, the amount of separation varying for different kinds of units. Essentially two kinds of interaction problems exist in manufacturing plants, those concerned with the fixed installation of subcritical units, as during storage or transportation, and those concerned with the movement of material from one process to another in the same plant. The latter interaction problems generally require both mechanical devices to insure separation and administrative controls to offset any decrease in safety introduced by the material movement. These controls are strongly dependent on individual plant practices.

Examples of nuclear safety in fixed installations are more closely related to the earlier considerations. Figure 5 shows a storage array of enriched uranium scrap in one-gallon, sealed pails mechanically arranged on 20-inch centers. Each pail is mass-limited and the resulting subcritical neutron multiplication factor is estimated using Pond's method mentioned earlier.<sup>6</sup> Then, the possible interaction is estimated from solid angle considerations. Fortunately, permissible solid angles have been devised by Oak Ridge and other groups and appear in several reports, in-

cluding the new Shipping Guide for U-235 Enriched Materials.<sup>10</sup> Generally, the mass of U-235 is limited to about 300 grams per pail to assure that each pail would be subcritical even if flooded. Under conditions of total flooding, the units would be effectively insulated from each other neutron-wise by the thick water layer. Hence, the more reactive situation of partial flooding ought to be the storage design basis.

Much experimental study of interaction has been done with massive fissionable metal. A result of these studies has been the *Nuclear Safety Guide* which recommends safe parameters to be used during storage and shipping.<sup>1</sup> The Guide specifies unit separations for different classes of material. For example, one should never ship more than 20 kg of unmoderated, fully enriched uranium in any single package. This mass would be subcritical even if immersed in water. Actually, many plants prefer to ship only up to 11 kg. In either kind of shipment, adequate separation from other, similar units is determined by using an iron exclusion frame or "bird-cage" surrounding the actual package.

The Nuclear Safety Guide recommends that

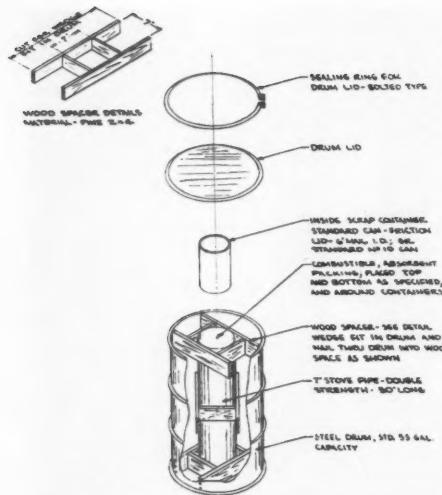


FIGURE 6. Uranium-bearing scrap container.

the U-235 density in a shipment of metallic, enriched uranium units should not exceed 4 kg/ft<sup>3</sup>. Hence, one can safely ship a reasonable number of units of enriched uranium in the 20-inch bird-cages if each cage contains 11 kg of U-235 since the density, 2.4 kg/ft<sup>3</sup>, U-235, is less than the recommended value.

In one of its regulations, the AEC recommends a modified 55-gallon drum for shipping uranium-bearing scrap. Figure 6 is a diagram of such a container. A centrally fixed stovepipe arrangement assures adequate separation among similar units.

## Summary

The ideas on criticality given above can now be summarized by expressing a few general guides to nuclear safety. The mass parameter of criticality has been stressed because many fabrication plants, which employ a series of batch processes, use it in determining nuclear safety. It is often more desirable to use dimensional limitations, since this approach reduces the administrative control needed. However, dimensional limits are more easily applied to fairly continuous processes or static situations, such as storage arrays. In either case, safety factors are applied to critical parameters to achieve safe values.

First, allowance must be made for the possibility of double-batching caused by human, analytical, or sampling errors. Therefore, there should be a factor of at least two between the critical mass and the mass value used. The

workers at Oak Ridge use a safety factor of 2.3 on mass.<sup>11</sup>

Secondly, the safety factor on volume or dimensional parameters is usually 1.3. The lower factor is used here since operating errors are less likely when these limits are feasible and errors in design and construction are quite unlikely.

When dimensional limits are used, great care must be taken that the values are correct. Dimensional limits usually apply to solution-like systems and must not be used for unmoderated uranium. For example, the recommended maximum thickness of a slab-like solution container is 1.4 inches, while the maximum thickness of an enriched uranium metal slab is 0.7 inches.<sup>12</sup>

Present practice dictates that *total flooding* of a process or storage area by water should not result in a critical configuration. For this reason, the data and analyses of fully reflected experiments are most useful. However, in some arrays the partially flooded situation can be more reactive and account must be taken of this possibility.

The smallest critical configurations involve finely divided and dispersed material. For this reason, the data derived from study of uranium solutions are usually applied to processes involving scrap solutions, chips, turnings, and sludges. Here, extreme care must be taken to account for the possible increase in the infinite multiplication of a system, due to changes in concentration caused when such systems are disturbed.

Nuclear safety should not depend on the occurrence of less than two unlikely events. As an example, consider the critical masses of the massive, fully enriched uranium metal sphere given in Table II. Recall that the minimum critical mass, unreflected, is about 48 kg of U-235. When completely water-reflected, the critical mass is about 22.5 kg. Therefore, the storage of 20 kg would be safe, unless more material were added concurrently with flooding. However, to account for double-batching during packing or unpacking, the usually recommended maximum mass is 11 kg.

In conclusion, I wish to emphasize that the ideas presented here do not represent a complete picture of nuclear safety problems. The general bases for criticality have been described. There are virtually an infinite number of possible fissionable systems in processing plants. Only a very few have been indicated. Further, the related problems of radiation alarm systems, of evacuation procedures, and of monitoring after a critical burst have not been described. However, it is hoped that some appreciation of the

scope of preventing unwanted criticality has been presented.

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#### MINERALS YEARBOOK

THE LATEST BUREAU OF MINES *Minerals Yearbook*, a comprehensive three-volume record of activities and developments in the Nation's mineral industries during 1958, was published in December 1959 by the Department of the Interior. Its three volumes are: Volume I—Metals and Nonmetals; Volume II—Fuels; and Volume III—Area Reports. Each volume includes summaries of important statistical information, discussions of significant technologic developments, detailed statistics on world production, and accounts of outstanding industrial developments both at home and abroad.

Copies can be obtained *only* from the Superintendent of Documents, Government Printing Office, Washington 25, D.C. Prices are: Volume I, \$4.00; Volume II, \$2.25; and Volume III, \$3.75. Individual chapters from each volume also are available at prices ranging from five cents to thirty-five cents per copy.

# Urinary Uranium Levels in Non-Exposed Individuals\*

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## Introduction

THE MOST widely used method for evaluating individual industrial exposures to uranium dust is urinary excretion measurements. Neuman,<sup>1</sup> using animal data, first established excretion levels of varying exposures. Eisenbud<sup>2</sup> and co-workers, summarized the average exposure and excretion levels for groups of employees working in the presence of uranium oxide dust. The general conclusion drawn from this work was that a group of individuals exposed to the maximum permissible concentration of uranium (50 micrograms per cubic meter, at that time) will excrete about 50 micrograms of uranium per liter. Excretion data from industrial exposures show levels of uranium of 1-10 micrograms per liter of urine for considerable numbers of personnel. A knowledge of the amount of uranium found in non-exposed personnel would be important in the evaluation of these minimal exposure levels.

Considerable work has been reported concerning the absorption of uranium by anion exchange resins. Kraus and associates<sup>3, 4</sup> have investigated extensively the absorption of uranium from chloride medium. The method described here isolates uranium from other inorganic constituents in urine prior to fluorimetry. Residual quantities of iron are removed by mercury cathode electrolysis.

The major limitation in the usable sensitivity of the fluorimetric analysis is the fluorescence of the sodium fluoride used in fusion. While this fluorescence is quite reproducible, it still masks that amount of uranium in urine of non-exposed personnel. The present technique allows a concentration factor of 200 and makes such analysis possible. The technique should also be applicable to water and effluent analysis.

Utilizing this procedure a series of analyses has been performed on one liter urine samples collected from twenty-six non-occupationally exposed personnel. Five of this group have been

followed for ten weeks with weekly determinations.

## Special Apparatus

*Mercury Cathode Apparatus*, Eberbach or similar apparatus.

*Uranium fluorimeter*.

*Ion Exchange Column and Resin*. The ion-exchange column is shown in Figure 1. Dowex 1 X-4 (100-200 mesh), analytical grade, was used in the column.

## Preparation of Resin Column

1. Wet sieve the resin and store in distilled water after a nonaqueous and aqueous extraction.

2. Fill the column with distilled water. Insert a glass wool plug at the bottom of the column to support the resin bed.

3. Transfer 10 milliliters of wet-settled resin to the column. Allow the resin bed to settle.

4. Place the stem of a 500 milliliter separatory funnel through a #6½ rubber stopper and insert in the top of the column.

5. Pass 500 milliliters of 1N HCl solution through the resin bed at a flow rate not exceeding five milliliters per minute.

6. Pass 7N HCl solution through the resin bed until the effluent is 7N in HCl.

## Regeneration of Resin Column

The resin column may be used for a number of separations if regenerated as follows:

1. Backwash the column with 500 milliliters of distilled water.

2. Pass 500 milliliters of 1N HCl through the resin bed.

3. Prepare the column by passing through 7N HCl until the effluent is 7N in HCl.

## Isolation Procedure

1. Transfer the sample to a 1500 ml beaker and add 150 ml of HNO<sub>3</sub>.

2. Evaporate to a 50 ml volume and add 100

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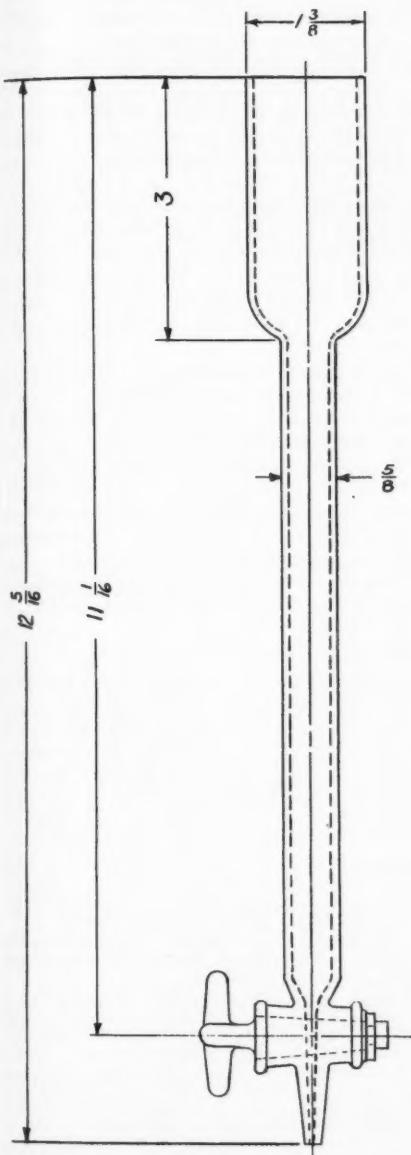


FIGURE 1. Design of ion exchange column used in the procedure described.

ml of  $\text{HNO}_3$  and 5-ml portions of 30%  $\text{H}_2\text{O}_2$ . (Destruction of organic material by wet ashing.)

3. Repeat step 2 until a white salt remains. Evaporate to dryness.

4. Dissolve the salts in 125 ml of distilled water and add 175 ml of HCl. (Complexing of uranium for absorption by anion exchanger.)

5. Transfer to the 500 ml separatory funnel and pass through the prepared ion exchange column at a flow rate not exceeding 2 ml per minute. Discard the effluent. (See Special Apparatus and Preparation of Resin Column. Exchange of uranium chloride complex.)

6. Pass 400 ml of 9N HCl through the resin bed at a flow rate not exceeding 5 ml per minute. Discard the effluent. (Removal of interfering material mechanically held by exchanger.)

TABLE I  
Uranium in Non-Exposed Personnel

Name	Micrograms of uranium per liter	Name	Micrograms of uranium per liter
GH.....	0.163	EH.....	0.082
SG.....	0.112	JK.....	0.071
CB.....	0.082	RM.....	0.056
GF.....	0.163	BS.....	0.087
JA.....	0.076	GW.....	0.082
DS.....	0.061	HS.....	0.092
ST.....	0.031	MO.....	0.150
PG.....	0.132	SS.....	0.214
JS.....	0.150	LC.....	0.132
AR.....	0.194	AH.....	0.046
JH.....	0.112	BG.....	0.117
IW.....	0.300	JG.....	0.296
IC.....	0.061	DF.....	0.050

TABLE II  
Uranium Concentration for Ten Sampling Weeks

Week	JA	GF	SG	PG	JS
	Micrograms of uranium per liter of urine				
1.....	.070	.180	.150	.140	.090
2.....	.210	.110	.150	.150	.200
3.....	.070	.090	.160	.150	.150
4.....	.170	.120	.150	.140	.120
5.....	.140	.130	.120	.150	.150
6.....	.120	.160	.140	.140	.130
7.....	.230	.150	.080	.120	.150
8.....	.160	.120	.140	.130	.160
9.....	.180	.080	.140	.160	.170
10.....	.150	.110	.170	.170	.180

TABLE III  
Statistical Study of Uranium Levels

	D/F	Mean Square	F Ratio	F Ratio 99%
Sampling time.....	9	4.78	.40	2.85
Individuals.....	4	16.50	1.37	3.94
Residual.....	36	12.80		

7. Pass 150 ml of 1*N* HCl through the resin bed at a flow rate not exceeding 2 ml per minute. Collect the effluent in a 250 ml beaker. (Elution of uranium from the ion exchange resin.)

8. Evaporate the effluent to dryness. Dissolve the residue in 50 ml of 0.3*N* sulfuric acid solutions. (Preparation of sample for mercury cathode electrolysis. See Special Apparatus.)

9. Add mercury to cover the bottom of the beaker and electrolyze the solution for one hour at one ampere. (Removal of iron.)

10. Filter the mercury from the solution and collect the filtrate in a 150 ml beaker. Evaporate to dryness. Add 5 ml of HNO<sub>3</sub> and evaporate to dryness. (Destruction of traces of organic material from resin.)

11. Dissolve the residue in 10-15 drops of HNO<sub>3</sub>, transfer to a 5 ml volumetric flask and dilute to volume. (Preparation of sample for fluorimetric analysis.)

### Fluorimetric Analysis

Present methods for the quantitative determination of uranium are based on the fluorimetric method of Price *et al.*<sup>5</sup> In our laboratory, triplicate 0.1-milliliter aliquots of the solution containing uranium are dried and flamed on a platinum dish and fused with 90 milligrams of sodium fluoride.<sup>6</sup> The fluorescence is measured by a fluorimeter<sup>7</sup> designed and constructed by the Instruments Division of the Health and Safety Laboratory.

Accurate analysis for uranium at the sub-microgram level must be concerned with the occurrence of the element in the reagents used. Each analysis for uranium in non-exposed personnel was preceded and followed by a blank determination using the same quantity of all reagents outlined in the procedure, and the same ion exchange column. The average value for this reagent blank was 0.0121 ± .0029 micrograms. Results reported in Tables I and II have this value subtracted.

### Results

The method presented allows the determination of 0.005 micrograms of uranium per liter of urine. Table I indicates that the excretion levels of non-exposed personnel are at least a factor of ten higher than this lower limit. A sodium fluoride fusion without added uranium ranges from 5-7 instrument deflections. A deflection unit is equivalent to 0.0001 microgram of uranium on the dish or one microgram per

liter. Aliquots of 0.1 milliliter from the final five milliliter volume of the urine samples analyzed gave deflections of 30 to 60 units. At this range, reading of the galvanometer is accurate to one-half of a deflection unit. The overall method including pipetting, fusion and reading of the galvanometer has been found to be accurate in this range to 100 ± 8% at the 95% confidence level.

The initial sampling program consisted of twenty-six personnel from the Health and Safety Laboratory who had no past history of industrial exposure to uranium. Analyses of these one liter urine samples showed a range of 0.030 to 0.300 microgram of uranium. Table I shows the results.

One-liter urine samples were collected weekly over a ten week period from five laboratory personnel. Table II reports the values for the uranium concentration. The results range from 0.070 to 0.230 microgram per liter of urine.

Table III summarizes an analysis of variance of the results reported in Table II. The main factors studied are the variation of uranium levels with individuals and sampling time. Within the limits of the experiment both factors are insignificant at the 99% confidence level.

### Summary

A range of urinary uranium levels has been established for twenty-six non-exposed laboratory personnel of 0.030 to 0.300 microgram per liter. Five of these individuals contributed weekly urine samples which did not vary significantly in uranium content over a ten week period.

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# The Inhalation Hazard from Dust-producing Operations in the Repair of Ships with Low-level Radioactive Contamination

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## Introduction

FOR THE man engaged in shipbuilding or ship repair, experience with radioactive contamination will come in working with nuclear propulsion plants or in repairing vessels which have engaged in nuclear warfare or tests. Considerable attention has been directed toward the establishment of safe practices related to the prevention of excessive exposure of personnel to nuclear radiations from sources external to the body. Radiological monitoring with a radiae instrument is undertaken to determine the intensity of radiation present. Criteria known as maximum permissible exposures are values which have been set as the maximum amount of radiation which the whole body or portions of the body can receive in weekly doses without deleterious effect on the health of an individual. Criteria regarding the maximum permissible concentration of radioisotopes in air have now been promulgated.<sup>1, 2</sup> However, efforts are needed to: (1) correlate the relative aerosol producing capability of the common industrial processes, (2) specify in detail approved safety devices for use while working with radioactive aerosols, (3) specify an approved method of measuring the radioactive concentration of an aerosol and (4) ultimately prepare a simple means of determining in the field, without resort to the laboratory, the degree of aerosol hazard created by an operation. The commonplace repair operations of sandblasting, welding, chipping, disc-sanding or wire-brushing can all produce dusts of radioactive particles when operations are performed on contaminated surfaces. Safety practices prescribe the use of respirators for personnel engaged in most of these operations but how effective are the standard respirator filters against

radiological contamination? What type of dust-producing operation will most likely create an aerosol of highest concentration? In other words, if there is a choice, do we know which operation is the safest in working with contaminated surfaces?

Since adequate information to answer these questions was not available in the directives and literature, the authors undertook a series of tests, modest in scope and more qualitative than quantitative in nature, to guide our thinking. The tests were performed on a vessel which had participated in recent nuclear tests and which still had moderate-level radioactive contamination.

The answers sought are considered important both from the standpoint of workman's health and shipyard economy. It is essential that the ship repair manager have clear-cut and realistic criteria, coupled with safe procedures for application at various levels of aerosol contamination, in order that personnel be adequately protected. At the same time it is essential that such protection be necessary and not excessive. While industrial safety and health are acknowledged to be paramount, the excessive protection which will result from compounding factors of safety rapidly increases the cost and duration of repair work.

## Description and Results of Tests

Selection of areas with as homogeneous a contamination as possible was of considerable importance if the relative degree of hazard of different surface cleaning operations was to be established. The ship's surface was quickly monitored with the probe of an AN/PDR-5 radiation detecting instrument since this instrument was more sensitive to beta radiation. Preliminary checks had shown the preponderant part of the contamination to be beta emitters. When a suitable area was located, the monitoring instrument was switched to the AN/PDR 27-F and readings were taken at six-inch intervals in

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The statements made and opinions expressed herein are those of the authors and not necessarily those of the Navy Department.

all directions over a sufficient area to permit sampling of each of the operations. Meter readings were taken at 1½ inches from the surface. Open window (for beta plus gamma radiation) and closed window (for gamma only) were made at each point. (To obtain the beta dose rate, the closed window (CW) reading was subtracted from the open window (OW) readings and the net reading multiplied by ten to determine the corrected beta dose rate.) It is understood that the beta dosage rates reported herein may require an additional correction factor based on studies now being conducted at NRDL. Open and closed window readings were averaged to give an average area reading. An attempt was made to mark off areas within 20% of the average. The probe tube of the AN/PDR 27-F was held at the 1½-inch mark by means of a thin rigid wire jig (tripod). After the areas had been

TABLE I  
Disc-sanding Operation

Sample Number	Radiation intensity of area corrected* beta (mrad)	Volume ft <sup>3</sup>	DPM**	XMAC†
Samples collected at breathing level of operators (1½-3 feet from operation)				
1	29.5	2.70	15,906	95
2	29.5	6.75	50,303	120
3	29.5	2.43	11,374	75
4	29.5	6.75	23,639	56
5	29.5	0.68	1,619	38
6	29.5	2.26	10,428	74
7	12.5	2.70	5,852	36
8	6.4	3.25	6,919	29
9	3.2	4.10	2,607	10
10	3.2	0.79	715	15
Inside general room air (Approx. 6 feet from operation)				
1	24	2.06	3,388	27
2	24	1.13	1,595	23
3	21		759	10
4	21		1,551	9.6
5	19	0.68	1,672	20
6	8	6.20	8,613	22
7	8	1.49	2,024	22
8	8	1.92	3,234	27
9	8	2.98	3,465	19
10	5	6.10	3,927	10
11	5	1.70	748	7.1
12	5	1.13	671	9.6
13	5	1.13	814	12

\* Corrected beta = (O.W. - C.W.) × 10 mrad.

\*\* The DPM (disintegrations per minute) value shown is the counter reading multiplied by 11 since the counter was known to count approx. 9% of the total disintegrations per information from NRDL.

† XMAC (The number of times the maximum allowable concentration is exceeded) where MAC = 10<sup>-9</sup> mc/cc.

delineated by a marking crayon, sampling equipment was set in position. This consisted of a wooden sampling head four inches square and two and one-half inches in depth. The air intake opening was 1.25-inch diameter over which was cemented a wire gauze to give rigidity to the filter paper used for collection of dust in this sampler. The type of filter paper used was Chemical Warfare Series #5 with a particle capture efficiency of 80-90%. The filter paper was held in place over the opening by means of a wood cover having the same size opening and fasten to the sampler head by two wing nuts. The sample head was connected to the Gast pump by a length of rubber tubing. This pump sampled at the rate of 1.3 cubic feet per minute. In addition to continuous sampling with the Gast pump, grab samples were also collected at the same time using the MSA Samplair of 640 cc per stroke capacity. During some runs three or four simultaneous samples were taken with additional equipment using a Jordan pump, MSA

TABLE II  
Welding Operation

Sample Number	Radiation intensity of area corrected* beta (mrad)	Volume ft <sup>3</sup>	DPM**	XMAC
Samples collected at breathing level of operators (1½-3 feet from operation)				
1	29.5	1.13	1,045	15.0
2	29.5	1.13	297	4.2
3	29.5	0.57	627	18.0
4	29.5	0.57	363	10.0
5	20.0	6.31	363	0.9
6	20.0	5.65	2,684	7.6
7	20.0	4.19	693	2.7
8	20.0	4.37	407	1.5
9	20.0	4.52	957	3.4
10	20.0	4.52	1,804	6.4
11	20.0	1.13	319	4.5
12	20.0	0.38	154	6.4
13	20.0	0.91	638	10.0
14	20.0	1.13	297	4.2
15	6.4	3.35	484	2.6
16	6.4	6.50	55	0.6
17	3.0	5.55	209	0.6
18	3.0	0.68	77	1.8
Inside general room air (6 feet from operation)				
1	7.0	2.26	110	0.75
2	7.0	2.26	110	0.70
3	7.0	2.26	55	0.39
4	5.0	4.52	88	0.31
5	5.0	1.42	143	1.20
6	5.0	1.42	110	0.92

\* See footnote Table I

\*\* See footnote Table I

Fixt-Flo Air Sampler, and a Wilson pump. Those collected with the Jordan and Wilson pumps were connected to sampling heads made of Coors Buchner funnels of 1.75 inches inside diameter that had been reduced to one-inch opening by means of a tight fitting rubber gasket 0.25 inch thick which was inserted flush into the funnel. A wire gauze was cemented to this gasket and the CWS #5 filter paper was inserted on top of the gauze and held in place by another tight fitting identical gasket. Samples were collected at various levels and distances as indicated on the Sample Data Charts, Tables I to VII. It will be noted that some samples were taken on deck areas protected from the wind by three-sided shields approximately three feet high, similar to those used in electric arc welding to protect other workers from directly viewing the arc. Figure 1 shows the arrangement during an electric arc welding test. Other samples were collected at various levels in an enclosed space (see Figure 2), as indicated in the data tables. In other instances samples were collected in the open. Figure 2 shows the conditions of sampling during the sandblast operations. Figure 3 shows the arrangement of equipment for sampling in the open at various distances.

At the termination of each operation the filter paper samples were collected from the continuous sampling device or grab sampler folded in two with the collected dust inside and placed in a properly identified envelope to be carried back to the laboratory. Here they were unfolded centered on a depression in an aluminum holder and placed under a Geiger Muller tube attached to a Geiger Muller Sealer Model 1000 with automatic timer for counting. The time in the counter varied depending on the count. Those samples that showed high counts immediately (*i.e.*, in the thousands) were counted only for five minutes, those with lower counts were given correspondingly longer counting times to reduce statistical error. Background readings were made at the beginning of each set of counts and background was checked from time to time during the readings. The usual background count per minute was the average of a ten minute run and occasionally a 30 to 60-minute check was made.

The data obtained from the air sampling tests are presented in Tables I through VI. All readings of surface intensity indicated were made with the AN/PDR 27F radiac instrument and converted to corrected beta values since the beta emitters, as previously noted were found

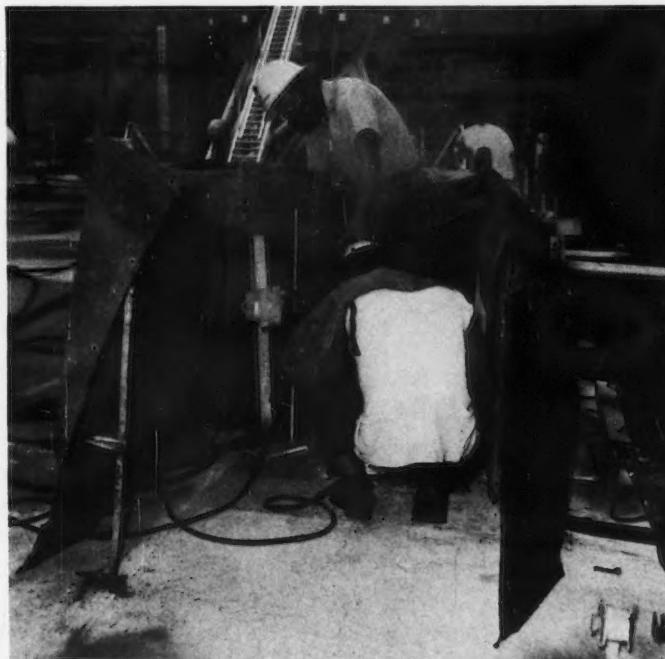


FIGURE 1. Sampling during a welding operation. (Official photograph U. S. Navy.)



FIGURE 2. Sampling during sandblast operation. (Official photograph U. S. Navy.)

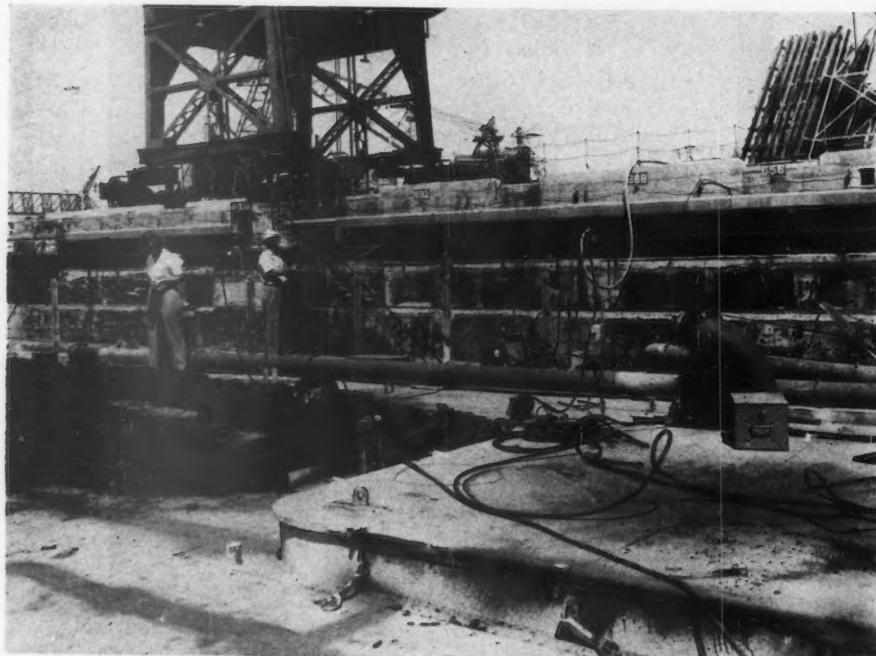


FIGURE 3. Sampling in the open at various distances. (Official photograph U. S. Navy.)

TABLE III  
Pneumatic Wire Brushing Operation

Samples collected at breathing level of operators (1½-3 feet from operation)

Sample Number	Radiation intensity of area corrected* beta (mrad)	Volume ft <sup>3</sup>	DPM**	XMAC
1	19.5	5.10	9,438	30
2	19.5	1.70	4,323	41
3	19.5	0.91	5,027	90
4	6.3	5.60	1,485	4.2
5	6.3	1.36	583	6.9

\* See footnote Table I

\*\* See footnote Table I

TABLE IV  
Pneumatic Chipping Operation

Sample Number	Radiation intensity of area corrected* beta (mrad)	Volume ft <sup>3</sup>	DPM**	XMAC
Samples collected at breathing level of operator (1½-3 feet from operation)				
1	29.5	14.90	2,288	2.5
2	29.5	4.52	220	0.78
3	19.0	4.80	506	1.7
4	19.0	3.02	671	3.6
5	19.0	4.11	957	3.7
6	19.0	2.26	418	2.6
7	19.0	2.26	198	1.4
8	19.0	2.26	440	3.1
9	19.0	2.26	352	2.5

Inside general room air (6 feet from operator)

1	8.0	9.26	55	0.09
2	8.0	13.90	308	0.36
3	8.0	2.26	44	0.31
4	8.0	2.26	77	0.55
5	8.0	2.26	55	0.39
6	8.0	2.26	154	1.10
7	8.0	2.26	77	0.55
8	5.0	4.10	110	0.43
9	5.0	4.52	44	0.16

\* See footnote Table I

\*\* See footnote Table I

to be predominant. The data presented in Figure 4 shows that disc sanding produces the most concentrated radioactive aerosol with wire brushing next in intensity. Welding and chipping follow in lesser amounts.

In general, the results indicated that the aerosol concentrations of radioactivity were variable, being particularly sensitive to air flow in the immediate area. This points up the importance

TABLE V  
Sandblasting Operation

Samples collected at distances indicated

Sample Number	Radiation intensity of area corrected* beta (mrad)	Distance from operation, feet	Volume ft <sup>3</sup>	DPM**	XMAC
Dry blasting					
1	15.0	35	7.6	473	1.00
2	15.0	60	14.5	341	0.38
3	15.0	60	23.9	407	0.27
4	15.0	80	13.6	143	0.17
5	11.3	28	5.03	577	1.70
6	11.3	53	10.0	253	0.40
7	11.3	53	16.2	407	0.40
8	11.3	73	9.04	143	0.25
9	21.5	35	5.03	2,013	6.40
10	21.5	60	10.0	704	1.10
11	21.5	60	16.0	1,485	1.50
12	21.5	80	6.05	396	1.00
13	21.5	100	6.05	55	0.15
Wet blasting					
14	12.2	35	4.85	88	0.29
15	12.2	60	9.70	33	0.05
16	12.2	60	15.90	88	0.09
17	12.2	80	8.60	22	0.04
18	12.2	40	1.70	22	0.21
19	13.4	20	3.20	55	0.27
20	13.4	40	6.44	88	0.22
21	13.4	30	4.95	198	0.63
22	13.4	25	1.57	66	0.67
23	13.4	25	0.94	132	2.20

\* See footnote Table I

\*\* See footnote Table I

of providing local exhaust ventilation to direct the dust and fumes away from the operator.

It was hoped to present the results in graphical form for use in the field, such as Figures 5 and 6, which could be used by the field supervisor to ascertain the need for respiratory protection as a function only of the type of operation, the surface radiation intensity and the distance of the operator from the dust-generating source. The charts presented are subject to such wide variability, as is apparent from an analysis of the data, that the authors are reluctant to recommend their use for anything but qualitative checks. The authors recognize the still existent need of using laboratory air sampling to determine with accuracy the aerosol concentrations being encountered. More precise, laboratory-controlled experiments must be made before the field supervisor can use such charts with reliability.

Relative to selection of filters the following comments are offered. Proper respirators should

TABLE VI  
Disc-sanding, Chipping and Welding  
Grab samples taken (6-10 inches from source).

Operation and Sample No.	Radiation intensity of area corrected <sup>a</sup> beta (mrad)	Volume ft <sup>3</sup>	DPM**	XMAC
Disc-sanding 1	29.5	2.06	58,240	400
" 2	29.5	2.06	36,036	280
" 3	29.5	1.13	38,896	550
" 4	29.5	0.113	3,278	460
" 5	29.5	0.226	3,388	240
" 6	14.4	0.181	2,651	240
" 7	14.4	1.13	14,223	200
" 8	12.0	0.791	10,934	220
" 9	12.0	1.24	4,697	61
" 10	6.4	0.68	9,658	230
" 11	6.4	0.90	6,028	110
Chipping 12	29.5	2.26	4,378	31
" 13	19.5	1.58	1,353	14
Welding 14	6.4	0.57	176	5.0†
" 15	3.0	0.57	132	3.8†

\* See footnote Table I

\*\* See footnote Table I

† Peculiar to the welding operation is the cone-shaped gaseous plume which results. It was observed that readings made in the plume were considerably higher than those outside the plume. The readings shown above were probably taken outside the gaseous plume.

be required for all of the operations discussed since the data show aerosol concentrations which exceeded the maximum allowable in nearly all cases. It would be of importance to know more about the relative particle sizes produced by these operations as this is essential in filter selection. The efficiency of the filter in protecting the respiratory system is a function of the dust particle size and the particle linear velocity. Tests were made to ascertain filter paper efficiencies using two filter pads in series, measuring the residue collected by each and comparing. This method is crude since it neglects any particle which may have sufficient velocity and minuteness to pass through the first paper and still have enough momentum remaining to pass through the second filter. The tests made showed that the MSA metal fume filter pad had an efficiency of at least 99.4% in the ranges in which we were working. From other studies it appears that the MSA 1106B type paper, an all-glass fibre paper with 7% binder has the highest efficiency of the papers tested.

#### Comments

It will be noted that no data is presented relative to alpha-emitters in the tests performed. This is so because the alpha counts made of the type contaminant with which we were working

TABLE VII  
Samples Collected on Unprotected Deck  
Wind averaging 200-300 ft/min. Occasional gusts to 600 ft/min. Corrected beta = 4.0. Wind in direction of samples but variable.

Operation	Volume of sample, ft <sup>3</sup>	Distance from operation	Duration of sampling, minutes	XMAC
Disc-sanding	14.65	B.Z. of operator	10.25	0.12
"	6.56	10' B.L.	10.25	0.04
"	21.08	10 "	10.25	0.06
"	512.50	25' "	10.25	0.06
"	2.26	25 "	—	0.16
Wire-brushing	22.3	B.Z. of operator	15.5	0.027
"	—	10' B.L.	15.5	0.000
"	31.89	10 "	15.5	0.035
"	775.00	25' "	15.5	0.011
"	0.79	5' Operator	—	0.96*
"	10.40	25' B.L.	—	0.027
Welding	21.00	B.Z. of operator	15.0	0.013
"	31.65	10' B.L.	15.0	0.018
"	—	10 "	15.0	0.000
"	750.00	25' "	15.0	0.004
"	2.26	10" "	—	0.080
"	2.26	25" "	—	0.000

B.Z. (Breathing Zone) of operator approximately 2 feet from deck in near vicinity of operation.

B.L. (Breathing Level) approximately 5.5-6.0 feet level

\* 5 feet from B.Z. of operator 2 feet above deck in direction of dust ejection. Note that at this distance the concentration is still below maximum allowable concentration.

were of a very low level and by BuMed Standards were not of a hazardous degree.

The additional comment is made that in specifying the need for positive flow clean air type masks for radioactive aerosol concentrations greater than ten times the maximum allowable concentration, use is made of the criteria stated in BuMed P-1325, 1951 ed. Chapter 3-3 (2) (c) which states: "Beta and/or gamma emitters.—The maximum permissible concentration of air contamination by the more hazardous beta-gamma emitting isotopes such as iodine, strontium, barium, *et cetera*, is considered to be approximately  $10^{-9}$  microcurie/cc of air. When the air concentration reaches this level, masks shall be worn, and should the concentration increase by a factor of 10 (*i.e.*, reach a concentration of  $10^{-8}$  microcurie/cc), the area shall be evacuated."

A strict interpretation of the foregoing would mean evacuation where a level of ten times the maximum permissible exposure is encountered. However, we recommend the use of positive flow, clean-air masks in such cases where industrial work must be done and the external radiation hazard does not exceed the Maximum Permissible Exposure. Such masks should be of the full-face type with particular care being given to a tight fit.

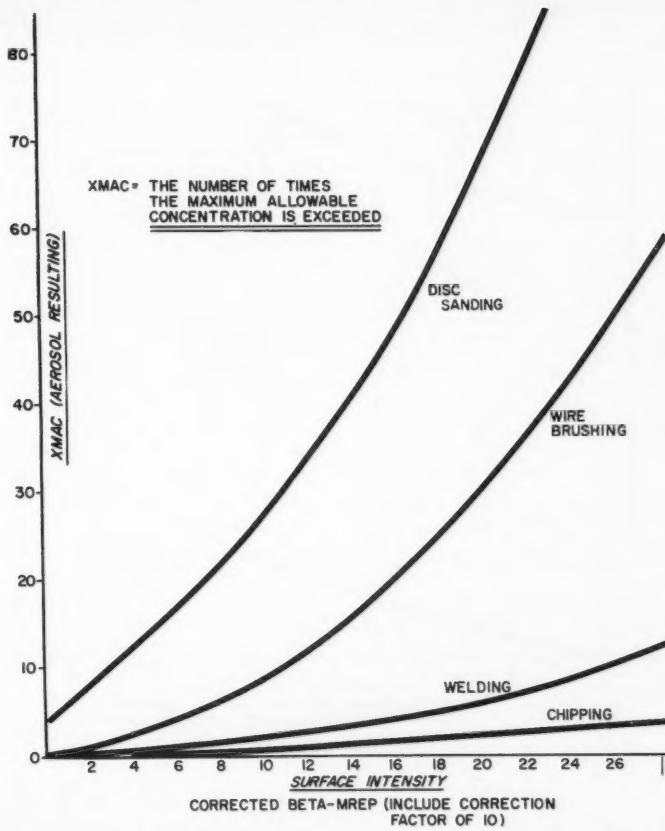


FIGURE 4. Plot of resulting aerosol radioactive concentration versus surface radiation intensity for four industrial operations.

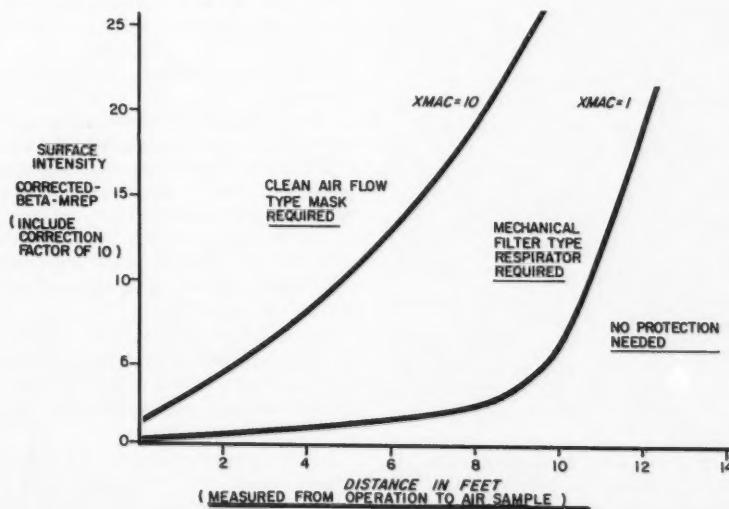


FIGURE 5. Disc-sanding in a confined space.

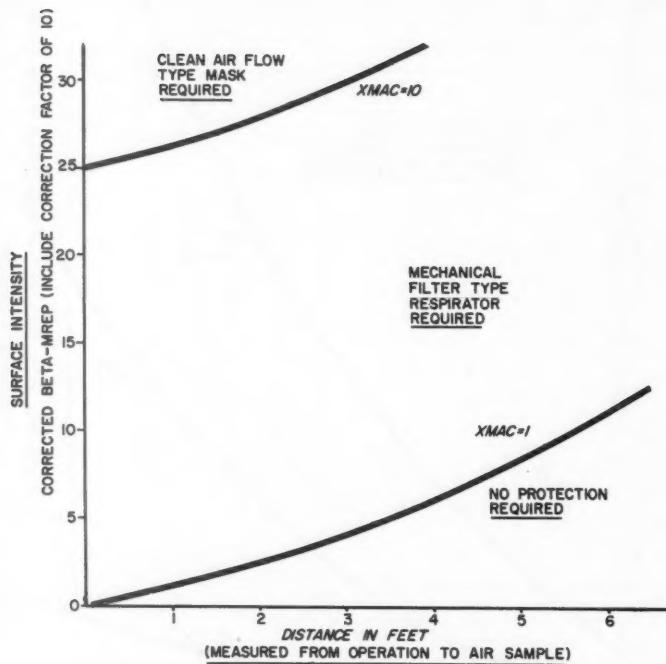


FIGURE 6. Welding.

### Conclusions

The authors have investigated and evaluated by test the aerosol hazard associated with dust-producing operations which will be encountered when personnel are engaged in the repair of ships having a low-level radioactive contamination. The conclusions reached as a result of these studies and tests are as follows:

(1) An internal radiation hazard can be created when performing any of the following operations in confined spaces on radiologically contaminated surfaces. In apparent order of severity of hazard these operations are: disc-sanding, pneumatic wire-brushing, welding, and pneumatic chipping. Sandblasting, even though unconfined, can also produce the aforementioned hazard, with wet sandblasting producing somewhat less aerosol than dry sandblasting.

(2) Local ventilation in the immediate area of the dust-producing operation, exhausting the dust and fumes away from the operator, is an important and effective means of reducing aerosol concentrations.

(3) The degree of hazard from air-contamination is dependent upon the following factors: type of operation, surface radiation intensity,

distance of personnel from operation, ventilation or air current present, and particle size.

(4) Mechanical filter type respirators with proper type filters appear to afford satisfactory protection against radioactive dusts produced from contaminated surfaces up to 4.0 mrad/hr measured at 1½ inches from the surface (i.e., the maximum surface intensity available for these tests).

(5) At higher (undetermined) levels of air contamination, it is expected that masks having a positive pressure flow of uncontaminated air or oxygen will be required to provide proper protection for the operator.

(6) No hazard to the wearer of the respirator when working on moderately contaminated surfaces is expected from the radiation of residue on respirator filters.

(7) A need is indicated for the development of a Navy-approved, practical combination welding mask and respirator unit for the use of the welder working on moderately contaminated surfaces.

(8) It is evident from the data presented that a need exists for better-controlled laboratory testing to obtain more accurate quantitative in-

formation regarding radioactive dust hazards arising from the various industrial operations.

(9) There is a need for the development of an instrument capable of measuring final clearance values. It is noted that the AN/PDR 27F is not suited for quantitative measurement. It is understood that correction factor curves for the AN/PDR 27C beta measurements are being prepared by the Naval Radiological Defense Laboratory.

(10) The degree of hazard which can result from dust-producing operations on surfaces having low-level radioactive contamination has been assessed. We feel certain now that, by using local exhaust ventilation and high-efficiency filter type respirators, any respiratory hazard to the operator can be eliminated when dusts are produced in working on surfaces having low-level radioactive contamination.

#### Acknowledgments

The efforts of Miss Elizabeth Stefee of the Industrial Hygiene Laboratory, Pearl Harbor Naval Shipyard, in assisting in the performance of the tests and analysis of the data were a great contribution in the preparation of this paper.

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#### STATISTICAL PLANNING OF EXPERIMENTS

THE USE OF statistical design or planning is assuming greater importance in studies and research in industrial hygiene as well as in other fields of science. The National Bureau of Standards conducts a continuing research program on methodology in the planning and analysis of physical science experiments. Two types of designs have received attention at NBS: fractional factorial designs, which are applicable to multi-factor experiments; and block designs, which are employed where measurements form homogenous sub-tests. The fractional factorial designs allow the experiment to be planned to that it will include only a fraction of the possible experimental combinations. The block designs balance out the effects of systematic errors and relieve the experimenter of much of the burden of reproducing on every occasion exact environmental conditions and exact experimental units.

Some bulletins and publications from NBS will be of value to those interested in these aspects of experimental design: (a) Fractional Factorial Experiment Designs for Factors at Two Levels, *NBS Applied Mathematics Series* 48 (1957); (b) Fractional Factorial Experiment Designs for Factors at Three Levels, *NBS Applied Mathematics Series* 54 (1959); (c) The Chain Block Design, *Biometrics* 9:127 (1953); (d) New Experimental Designs for Paired Observations, *J. Research NBS* 53:191 (1954).

# Survey of Current Status of Raynaud's Phenomenon of Occupational Origin

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## Introduction

REPORTS have appeared, both in the American and European literature in the past 50 years, relating hand and forearm disability to vibration from work tools. Close agreement on the physiologic and physical findings described by investigators from both continents has been noted. The disorders resulting from the use of these tools involve blood vessels, nerves, muscles, and joints.

In 1911, Loriga<sup>1</sup> in Rome first described the relationship between the use of a vibratory tool and the Raynaud's phenomenon. In 1918 Alice Hamilton, et al.<sup>2</sup> made a detailed study of miners using vibratory tools in the Indiana limestone quarries. Sporadic reports have appeared in the literature since then without adding significantly to her findings until Dart<sup>3</sup> and Peters<sup>4</sup> in this country and Hunter, et al.<sup>5</sup> in England published their observations. Dart and Peters reported their findings on workers using hand-held rotary tools with speeds up to 60,000 rpm (revolutions per minute). Hunter, et al. showed that the critical vibratory rate for the onset of Raynaud's phenomenon was between 2,000 and 3,000 rpm. Agate and Druett,<sup>6</sup> recognizing the lack of information on the relationship between the frequency and amplitude of the vibrations from the tools to this disease, made a detailed study of these characteristics of the tools and correlated their observations with the clinical findings in the workers using the tools. A more complete and detailed history of this disease may be obtained from the reviews and reports by Dart,<sup>3</sup> Walker and Gurdjian,<sup>7</sup> Hoerner<sup>8</sup> and Agate.<sup>6,9</sup> Up until World War II, most tools in this category operated at less than 10,000 rpm. Since then because of the nature of new work, speeds were gradually increased to 60,000 rpm with recent indication that speeds up to 100,000 rpm

will be used. Most of the studies reported in the literature, with few exceptions, do not include information concerning: (a) the number of workers exposed to vibration from hand-held tools, (b) the number exposed and showing changes attributable to vibration, (c) the amplitude and frequency of the vibrations, (d) the duration of their exposure, and (e) the manner in which the neurovascular and musculotendinous changes are produced.

The Committee on Physical Agents<sup>10</sup> reported on "The Physical Agents Potentially Hazardous to Industrial Personnel" at the Ninth Annual Congress on Industrial Health in 1949. Included in the list of the mechanical vibrating spectrum was vibratory contact. They gave definition and origin of vibrations, samples of occupational sources, injurious effects, and mechanism of action. Their estimate of the total number of persons involved was given as 100,000. They recommended, "A comprehensive study to determine injury threshold; development of physiol. and psychol. tests to determine extent of injury." No estimate on the incidence of disease due to vibratory tools was suggested.

Initially, our intent was to study further the clinical and physiologic effects resulting from high frequency vibrations from small hand-held tools. However, we soon realized from a preliminary survey that no figures were available on the incidence of the disease and also that the disease may be on the wane. This was also true concerning the larger tools with slower cycles. The purpose of the survey reported here was to determine the incidence and severity of this condition in the United States before considering any laboratory research on this problem.

## Methods and Results

It is recognized that there are various sources of vibration which create different effects. There are those vibrations imparted to the whole body of operators of trucks, buses, aircraft, trains, and ships, whereas certain heavy pneumatic tools weighing 40 to 80 pounds, such as jack-

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hammers, roadrippers, and rock drills with frequencies up to 2000 beats per minute cause effects predominantly in the hands, arms and shoulders, and manifested as muscular soreness and joint damage that may become permanent after years of using the tools. Since there is considerable knowledge about the effects of the low speed tools, and the Defense Department and private institutions were making intensive study of the effect of vibrations on the whole body, our survey was intentionally restricted to those effects resulting from hand-held tools with speeds up to the maximum currently in use, about 60,000 rpm. For the purpose of this survey, vibrating tools were defined as any portable or semi-portable beating or rotating tools, which during their operation transmit vibrations to the human body.

There is close agreement amongst investigators both here and abroad on the clinical and physical findings. Hunt<sup>11</sup> likens the symptoms to Raynaud's phenomenon and defines it as "intermittent pallor or cyanosis of the extremities, precipitated by exposures to cold, without clinical evidence of blockage of the large peripheral vessels and with nutritional lesions, if present at all, limited to the skin." In view of the many names given to this disease and the careful distinction Hunt made between Raynaud's phenomenon and Raynaud's disease, Agate<sup>6</sup> has suggested the use of the term "Raynaud's phenomenon of occupational origin."

An estimate of the number of workers using such tools was made with the aid of the following:

1. 1950 U. S. *Census of Population Report*. P-E No. 10. Reprint of Volume IV, Part 1, Chapter C (Detailed statistics of occupation by industry).
2. 1950 U. S. *Census of Population. Classified Index of Occupations and Industries*.
3. *Dictionary of Occupational Titles*, Volumes I and II, 2nd edition.
4. *Occupational Outlook Handbook, Bulletin #998*, 1951 U. S. Department of Labor.
5. *Physical Demands and Capacities Analysis of the Ship Building Industry*, War Manpower Commission, Permanente Foundation (now Kaiser Foundation) Oakland, California.

From the foregoing, it was estimated that about 440,000 workers in the United States use these tools. This was discussed with a representative of one of the largest tool manufacturing companies in the United States, and his estimate, based on company information, was that there are about 2,000,000 workers using vibratory tools. The U. S. Department of Labor repre-

sentatives estimated that there are nearer three or four million workers in this category. It is readily apparent from this disparity in estimates that a good approximation of the number of workers using such tools is not available.

Letters of inquiry were sent to fifty State, county and city industrial health agencies selected from the *Directory of Governmental Industrial Hygiene Personnel* requesting the following specific information:

(1) The numbers of workers using such tools; their job categories; and the industries in which they are employed.

(2) The numbers and categories of workers who report distress from sustained use, the duration of use of the tools, the symptoms and complaints and the tools responsible in these instances.

Replies were received from 43 States and cities. Five States reported on the number of workers using such tools, strongly emphasizing that their figures were but rough estimates. Four States reported compensation claims, not necessarily paid, for injury due to use of such tools. The remaining 34 States and cities had no information concerning this problem. Thus little appears to have been reported in the States and even though this disease entity is known, apparently few physicians are reporting its occurrence even if they have encountered it.

Similar letters of inquiry were sent to the chief industrial physicians of nine large automotive and aircraft manufacturers in this country. Their replies were essentially the same as above. Some mentioned that the disease was prevalent during World War II. Others stated that they had no knowledge of this disease appearing in their industry during the last ten years. The chief industrial physician from one of the large automobile manufacturers estimated that 50,000 out of 480,000 of their employees used such tools but they had no clear cut cases of Raynaud's phenomenon of occupational origin.

Subsequently, at a meeting with industrial physicians from the leading auto manufacturers one of us (MMU) concluded that the pathologic effect of vibratory tools is not a problem in their respective establishments. Rarely do they see cases in their clinics, nor do they recall any cases involving claims for compensation. All are of the opinion that the problem is not significant. They attribute this to increased automation of industrial processes and improved pneumatic tools.

Visits were made both locally and in other parts of the country with the intention of seeing cases of this disease. Eleven large plants employing between 1500 and 25,000 workers where large

numbers of workers were known to use vibratory tools were visited. Similarly seven smaller plants employing less than 1500 were visited. We saw the operations, and examined and questioned many of the workers about the disease. In none of these visits were we able to find a case of Raynaud's phenomenon of occupational origin.

Arrangements were made in collaboration with the Surgeon General of the U. S. Air Force Air Materiel Command to collect information pertinent to this problem from the various Air Materiel Command bases. Reports were received from nine air bases where records of the last five years were reviewed. The estimate showed that about 7000 workers were employed using vibratory tools. None of the reporting physicians observed any cases of the disease and no compensation claims were made. Lt. Col. Boysen, Deputy Surgeon, Air Materiel Command, stated, "I think it is probably most significant that there have been no Bureau of Employee Compensation claims attributable to this occupational exposure."

Our search for the number of cases reported in the world literature in the past 50 years revealed 1235 workers had been studied. This number includes only those we believed to be Raynaud's phenomenon of occupational origin.

### Discussion and Conclusions

This study was originally designed as a preliminary survey of the effects of vibratory tools on workers and to determine specifically the magnitude of the problem, to review the literature; and to determine the patho-physiology; all in an effort to determine whether or not further study of Raynaud's phenomenon of occupational origin would be justified. It was not surprising that specific answers to our questions were not available because of the inadequate reports of occupational diseases both at the State and Federal levels. No State or city health agency had specific figures on the incidence of the disease. The impression from industry is that Raynaud's phenomenon of occupational origin from vibrations from hand-held tools is practically non-existent since no cases have been reported in the last ten years and no compensation claims for this disease have been paid.

The bulk of the literature reviewed contained isolated reports of small numbers of cases. Only a few were well documented studies. As far as could be determined, no cases have been reported in the American literature during the last ten years but sporadic cases of the disease have occurred in Europe. From our own investigation and from discussions with others in

the field of occupational health, the general impression is gained that there are fewer cases occurring because of several factors: (a) The manufacturers of these tools have become aware of the pathologic effects and through research have improved their tools. (b) Production schedules are not nearly so demanding as during the war. Thus, with a more leisurely pace, workers have longer rest periods and shorter exposures. Now workers generally work about 40 hours per week as compared to about 60 hours during the war. (c) Today those workers who demonstrate early a susceptibility to this disease are transferred to other jobs. This was often impossible during the war period due to the labor shortage. (d) Automation has eliminated the need of manual operation of many of these tools. (e) Since the disease has been recognized as a potential hazard by industry, work plans have been arranged so that workers use the tools intermittently, thus reducing the hazard.

There is no doubt that the patho-physiology of the mechanism of Raynaud's phenomenon of occupational origin has not been adequately explained and that more information about it would be desirable. It is probable that Raynaud's phenomenon of occupational origin has not been eliminated completely, but it is of such low incidence at present that it falls in the category of a minor problem. The question arises as to whether or not the disease is becoming extinct.

### Summary

A preliminary survey of the literature on the incidence of Raynaud's phenomenon of occupational origin in this country revealed a conspicuous lack of information concerning both the number of workers affected and the number using small hand-held vibratory tools. An attempt was made to estimate the number of workers using vibratory tools and the number afflicted with Raynaud's phenomenon of occupational origin.

All the information thus gathered indicates that Raynaud's phenomenon of occupational origin may not be completely eradicated but that it may have become an uncommon occupational disease approaching extinction in this country.

### Acknowledgments

We wish to thank Brig. General Edward J. Tracy, USAF (MC) Surgeon General, and Lt. Col. John E. Boysen, USAF (MC) Deputy Surgeon, for their cooperation in supplying the information on the employees at the various Air Materiel Command bases.

We also wish to extend our most sincere thanks to the many other people who took time to answer our letters, to those who graciously gave us their time during our visits to the different plants and to the many others with whom we conferred and discussed our study.

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#### AIHA CUMULATIVE INDEX

A CUMULATIVE INDEX of the American Industrial Hygiene Association Quarterly from 1940 through 1957 (Volumes 1 through 18) has been completed. This Index was compiled in conjunction with the offering of complete sets of bound volumes of the Quarterly and provides a valuable key to a great deal of important information on industrial hygiene published over these eighteen years. Because of its value as a reference source, the Cumulative Index is being made available for purchase as a separate item. The Index is available in either soft or hard cover until further notice. The price schedule is:

Members: soft cover \$10.00      Non-members: soft cover \$15.00  
hard cover 15.00      hard cover 20.00

Orders and inquiries should be directed to Executive Secretary, American Industrial Hygiene Association, 14125 Prevost, Detroit 27, Michigan.

# An Investigation of Lens Opacity on Personnel Operating a Portable Nuclear Reactor

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ONE OF THE least understood, but still one of the most significant types of radiological damage is the production of radiation induced opacities in the lens of the eye. Although the mechanisms which produce these opacities are only vaguely understood, it is known that neutron radiation is an effective cause. For this reason we, at Convair-Fort Worth, feel that it is necessary to maintain a close surveillance of the eye tissues of employees who in their work are exposed to neutron radiation. This surveillance is accomplished through the administration of routine slit-lens eye examinations. More than 655 of these examinations have been administered over the past four and one-half years, and presently we shall discuss some of our findings in them. Before presenting these findings, we would like to give a brief summary of nuclear activities at Convair-Fort Worth.

Convair-Fort Worth is one of the major contractors involved in the study of nuclear propulsion for aircraft, and as such, conducts many and varied experiments having to do with radiation shielding, the scattering of radiation, the effects of radiation on aircraft parts, components and materials, the hazards inherent in nuclear powered flight, and so forth. In the course of these experiments some of our employees are necessarily exposed to many types and intensities of nuclear radiation—from x-rays to fast neutrons. The neutron radiation which we are concerned with here is produced by forty-eight encapsulated polonium-beryllium sources, ranging in strength from one to fifty curies or from the order of  $1 \times 10^6$  to  $1 \times 10^7$  neutrons per second emitted, and one radium-beryllium source having one curie of radium, and emitting  $1 \times 10^7$  neutrons per second. Also considered is radiation from our two nuclear reactors, the Ground Test Reactor and the Aircraft Shield Test Reactor.

These two reactors are, perhaps, unique in the nuclear industry today. This is due to their extreme portability and flexibility of operation. Both have been operated in the megawatt range, and both have been operated at high power levels with only a minimum of shielding. Both have

been operated in many locations, ranging from deep under water to high in the air.

The Ground Test Reactor (Convair's first) was first made critical in October, 1953. This reactor, a swimming pool type, is used for shielding studies, radiation effects studies, radiation scattering and so forth. The reactor was at first operated only in the swimming pool type tank where it achieved criticality but later it was operated in small portable moderator tanks. Some of these tanks provide less than six inches of water around the reactor core, and even this is not intended to be a shield, but only a neutron moderator. While in such a tank, the reactor has been operated at relatively high power levels while suspended seventy-five feet above the ground. The ground test reactor is capable of operating at a power level up to three megawatts, in the partially empty swimming pool. Some of the dose rates originating from this reactor, and in which personnel must occasionally work, have been as high as seventy rem per hour of gamma radiation, and twenty-five rem per hour of neutron radiation.

The second of Convair's reactors, The Aircraft Shield Test Reactor, was first made critical in November, 1954. It has the distinction of being the first reactor ever to operate while being carried aloft in an airplane. This reactor made forty-five flights in a modified B-36 bomber, but was not used to power the plane. During these flights it was operated at power levels as high as one megawatt. Of course, due to the serious shielding weight problem, the reactor shielding was minimal during these flights. Even though the shielding was minimal it was adequate to protect the crew and there was no evidence of radiation damage, ocular or otherwise, discovered in any examination of any crew member. Their total dose was less than the maximum permissible level allowed for industrial workers. The Aircraft Shield Test Reactor has also been operated in many configurations on the ground and in the swimming pool. Power levels and dose rates have been very high. Some of our employees have worked in gamma fields as high as twenty-five rem per hour and

neutron fields as high as five rem per hour while working with and around this reactor.

All the sources of radiation which I have just mentioned, in addition to many others which are not related to the problem of neutron induced opacities in eye lens tissue, constitute the situation which requires Convair-Fort Worth to conduct a complete program of radiological health protection. Our Medical Section administers a widely diversified health physics program which includes area and job monitoring, personnel monitoring, environmental monitoring and all the other aspects of radiological protection. The medical aspects of this program include the administration of routine and special nuclear physical examinations and the maintenance of a complete radiation history for each employee on the nuclear projects. This radiation history consists of all available information on the employee's radiation exposure, both prior to and during his period of employment at Convair-Fort Worth. This record also includes a report of the findings of the slit-lens eye examinations of any employee exposed to neutron radiation. These slit-lens eye examinations are administered at yearly intervals by Dr. C. Harold Beasley, consultant ophthalmologist. During the past 4½ years 655 of these examinations have been given. The data from these have been assembled and several interesting facts have come to light.

But first we shall briefly describe the crystalline lens. It is a transparent, biconvex, circular structure about 11 mm in diameter and between 3.6 mm to 3.9 mm thick at the center. It consists of an anterior and a posterior surface. The center of the anterior surface is termed the anterior pole of the lens and the center of the posterior surface is termed the posterior pole of the lens. The two surfaces meet at the circumference in a rounded edge called the equator. The lens is enclosed in a structureless elastic capsule,<sup>1</sup> and is avascular, and has no effective cooling system.

In these examinations, cataractous changes were considered as opacities of the lens cortex, capsule, or both. It is known that cataracts can result from exposure to very short waves of radiant energy. These rays usually cause degeneration in the posterior cortical lens fibers in months or years after exposure. Some investigators feel that an important component in its pathogenesis is the destruction of epithelial cells which later migrate to this area.<sup>2</sup> Donaldson states that the opacities are confined to this region until very late. And the cortex as a whole remains clear except for this very small portion in front of the posterior capsule. This is unlike

senile cataracts and cataracta complicata in which the cortex does not remain clear.<sup>3</sup> Some investigators have described these opacities as "doughnut-shape" but actually this is not entirely characteristic.<sup>4</sup> It is known that there is individual sensitivity to this type of radiation and it is not possible to determine a minimal safe dosage for any one person. Cataracts may result from amounts of radiation that do not cause clinical disturbances in other parts of the body.<sup>5</sup> Some lenses will tolerate a lot more exposure than others.

Investigation of the victims of the two atomic bomb attacks on Japan revealed that of the 8,000 exposed survivors there were ten cases of severe cataracts, 25 cases with slightly impaired vision and 200 with minimal lenticular changes detectable only by careful slit-lens examination by trained personnel.<sup>6</sup> These individuals were within 3600 feet of the bomb burst, and it is impossible to calculate their exposure. So far as is known 14 people in the United States have developed radiation cataracts as a result of cyclotron induced radiation exposure. These people received an unknown amount of gamma and neutron radiation to the head region.<sup>5</sup>

Yearly examination of those employees subject to neutron radiation exposures have been made. The age of the individuals examined varied from 23 to 57 years. Although none of these people has received excessive radiation exposure, it is of interest to present the findings.

These workers were examined approximately one hour after the local use of 10 per cent Phenylephrine, two drops in each eye, five minutes apart for three instillations. Mydriasis was done only after preliminary inspection revealed the anterior chambers to be deep. The lenses were observed with the slit-lamp microscope and careful notations were made as to whether any cataractous changes were present, and if so the character of these changes.

Lens opacities were found in 24 of the 655 examinations performed; 15 of these were of the congenital variety and nine were developmental.

#### Congenital Opacities

The congenital group was classified into three types of opacities and they were found in an age group from 23 to 42 years. These classifications were (1) Sutural, (2) Lamellar, and (3) Perinuclear Punctate opacities:

- (1) *Sutural:* Of this variety two were classified as sutural. These opacities are seen in the nucleus where the fibers meet an-

teriorly and posteriorly in a Y-shaped and inverted Y configuration. They can interfere with vision. In these cases over the 4½ year period, one had no neutron exposure and the other had a total of 68 millirem of neutrons. The total beta-gamma dose of both was 436 millirem.

(2) *Lamellar*: In the lamellar type of opacities six individuals were found to fall within this classification. Lamellar cataracts are congenital or occur in infancy. There is some hereditary tendency in their occurrence. They usually remain stationary but occasionally become complete to involve the entire lens. They do cause interference of vision. In this group of six, four had no neutron exposure, one had a total of 920 millirem exposure, and one had a total of 1045 millirem exposure to neutrons. The highest exposure of an individual in this group was 8504 millirem and this was all beta-gamma. Of this group, the one with 1045 millirem of neutrons had a total of 390 millirem beta-gamma, giving him a combined total of 1435 millirem.

(3) *Punctate*: Seven employees were found to have punctate opacities. These are defects of growth of the lens fibers occurring in childhood or at puberty. They are stationary and cause no visual defect. All but one in this group had received some neutron exposure. The lowest being 75 millirem and the highest being 1403 millirem. The individual with the highest neutron exposure, which was 1403 millirem, also had the highest total exposure which was 5052 millirem of both neutron and beta-gamma combined. Incidentally, the age of this employee was 42 and the oldest in the entire congenital group.

#### Developmental Opacities

In this classification we have placed those opacities which were not of congenital or hereditary nature. All of these developmental opacities were manifested by spoke-like cataracts in the cortex. Most of them were at the equator, and found in an age group varying from 31 to 57 years. This group consisted of nine employees, four of whom had no neutron exposure. The highest total neutron exposure was 2168 millirem, and was in an individual who was 54 years old. The highest total exposure was 8150 millirem of which 1247 millirem were due to neutrons. Incidentally, the oldest member of the

group (57 years) had no neutron exposure, and had received only 69 millirem beta-gamma.

Not included in the group of 24, three individuals who had persistent pupillary membranes were found, and in one of which was associated an anterior capsular opacity. This is of interest in that these persistent pupillary membranes at times can be confused with lens opacity; however, they are entirely congenital in origin and occur as a remnant in the fetal development of the pupil.

Although none of these people received excessive exposure this study is of value in that it does establish the presence of lens opacity prior to employment or exposure. This could be of value from the standpoint of compensation in the event of litigation. Although some believe that irradiation does not hasten the development of other types of cataracts.<sup>5</sup> Only one of these individuals had decreased acuity as a result of the lens opacity. This occurred in a case of lamellar cataracts, one of the congenital variety, and he was the only employee with cataracts who already was aware of this condition.

#### Summary

We recognize the radiological health problems inherent in the operation of high power reactors, especially those such as we must deal with, which are often operated with only a minimum shielding. In order to assure each of our employees that he will be protected against the damaging effects of nuclear radiation, we have established a complete health physics program and each employee is periodically examined, so that any radiobiological damage will be quickly detected. Employees who work with neutron radiation are given additional routine slit-lens eye examinations. The findings of these examinations are recorded as part of the radiation history of the employee. During the past 4½ years, 655 slit-lens examinations have been done, and 24 employees were found to have non-radiation induced opacities.

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# Determination of $\text{NO}_2$ and $\text{NO}$ in Air

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THE toxic oxides of nitrogen which are commonly encountered in the industrial atmospheres, and which are of particular interest to the industrial hygienist, are nitric oxide ( $\text{NO}$ ), nitrogen dioxide ( $\text{NO}_2$ ) and nitrogen tetroxide ( $\text{N}_2\text{O}_4$ ). These gases occur together in varying proportions, depending on their source and other factors.

Nitric oxide is a colorless gas which boils at  $-151^\circ\text{C}$ ; it is the oxide formed in welding and other high temperature operations. Wade<sup>1</sup> states that at high concentrations, on the order of 1000 ppm (parts per million by volume), the nitric oxide in air is rapidly oxidized to  $\text{NO}_2$ , but that in lower concentrations, on the order of 10 to 50 ppm, the oxidation occurs rather slowly. Nitric oxide causes cyanosis, but in low concentrations its toxicological effect is relatively minor. A Maximum Acceptable Concentration for  $\text{NO}$  in air has not yet been established.

Nitrogen dioxide is a reddish brown gas which exists in equilibrium with its dimer, the colorless  $\text{N}_2\text{O}_4$ . At  $25^\circ\text{C}$  there is approximately 20 per cent  $\text{NO}_2$  in equilibrium with 80 per cent  $\text{N}_2\text{O}_4$ , by weight. The boiling point of  $\text{NO}_2$  is  $21.3^\circ\text{C}$ . Industrial sources of these oxides of nitrogen include metal pickling with nitric acid, which produces varying proportions of  $\text{NO}$ ,  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$ , and thermal decomposition of metallic nitrates, which produces  $\text{NO}_2$ . A MAC of 5 ppm has been established for  $\text{NO}_2$ , which is extremely toxic.

For many years the collection of atmospheric samples in evacuated flasks, and their subsequent determination by the phenoldisulfonic acid method,<sup>2</sup> was generally recognized by industrial hygiene chemists as the most reliable method for the determination of oxides of nitrogen in air. In recent years the accuracy of this method has been questioned,<sup>3, 4</sup> and the use of a Griess-Ilosvay reagent, which determines the nitrite resulting from the solution of  $\text{NO}_2$  in the aqueous reagent, has been reported<sup>4</sup> to be more accurate, more rapid and specific for nitrogen dioxide.

The phenoldisulfonic acid method has been convenient for determining nitrogen dioxide as well as mixtures of nitrogen dioxide, nitric oxide,

and nitric acid vapor, and any question of the reliability of the method should be resolved. The use of Griess-Ilosvay reagents for analysis of field samples indicated that color development time was uncertain, and that these reagents were not specific for nitrogen dioxide since they reacted significantly with nitric oxide. A study was therefore made to determine the reliability and accuracy of both the phenoldisulfonic acid method, and of methods using a Griess-Ilosvay type reagent.

Standardization of nitrite reagents has previously been based on an empirical relationship between a metallic nitrite solution and the nitrite resulting from the solution of nitrogen dioxide in the aqueous reagent. In order to avoid the use of this uncertain empirical relationship, as well as to facilitate the study of these methods, a simple rapid method has been developed for the preparation of known concentrations of nitrogen dioxide in air and nitrogen.

## Reagents and Apparatus

All aqueous reagents were prepared from redistilled water. Reagent grade chemicals or the best commercial grade available were used in reagent preparation.

### Griess-Ilosvay Reagents for Determination of Nitrite:

#### Reagent A<sup>5</sup>

- 140 ml glacial acetic acid added to 1000 ml water.
- 0.1 gram sulfanilic acid dissolved with slight warming in 300 ml solution (a).
- 0.2 gram of 1-naphthylamine is dissolved in 40 ml water by boiling and the solution poured into 300 ml of solution (a). A short time before use, equal parts of solutions (b) and (c) are mixed for use as the absorbing reagent.

#### Reagent B<sup>5</sup>

One liter contains 0.1 gm of N-(1-naphthyl)-ethylenediamine dihydrochloride, 0.4 gm of sulfanilamide, and 9.5 grams of tar-

taric acid. These reagents may be ground together into a mixed powder. When this is done 100 mg of reagent is added to 10 ml of water for use in sampling. The dry reagent may be stored for a year if kept dry and in the dark.

#### Reagent C<sup>4</sup>

Dissolve 5 grams of sulfanilic acid in almost a liter of water containing 140 ml of glacial acetic acid. Add 20 ml of 0.1% N-(1-naphthyl)-ethylenediamine dihydrochloride, and dilute to one liter.

#### Phenoldisulfonic Acid Method Reagents.<sup>2</sup>

Absorbing solution: This consists of N/10 sulfuric acid solution with 0.5 ml of 30 per cent H<sub>2</sub>O<sub>2</sub> per liter. Phenoldisulfonic acid (A.P.H.A.) and reagent grade ammonium hydroxide are used for color development.

Silica Gel: Six to sixteen mesh silica gel was boiled with concentrated hydrochloric acid for 30 minutes, and then washed with 10 successive washes of hot distilled water, until no acid remained. The silica gel was dried at 300°C for two hours. After cleaning, which reduced the particle size, the silica gel was sieved, and 12-20 mesh silica gel separated for use. Silica gel adsorption tubes were prepared by placing 4 grams of 12-20 mesh silica gel in 8 mm OD glass tubes containing wool plugs at each end. The tubes were approximately six inches long, with a slight restriction in one end to prevent the silica gel from being pulled out during sampling.

#### Apparatus:

Spectrophotometer: Beckman Model DU, using one-cm corex cells.

Vacuum flasks: 500 ml spherical flasks, with rotating cap, similar to the Sheppard-type vacuum bottle.

Syringes: 50 ml, Luer, graduated in 5-ml units.

#### Procedures

##### Preparation of Known Concentrations of Nitrogen Dioxide and Nitric Oxide

An accurate and relatively simple method was devised for the laboratory preparation of known concentrations of nitrogen dioxide in air by thermal decomposition of lead nitrate. Lead nitrate decomposes into lead oxide, nitrogen dioxide and oxygen, according to the equation,<sup>6</sup>



Not only is the lead nitrate crystal much

easier to manipulate than gaseous nitrogen dioxide, but the ratio of reacting weights shows that the ratio of lead nitrate to nitrogen dioxide is a little less than 4 to 1, which is a considerable advantage in accuracy over weighing nitrogen dioxide directly. In addition, it is much simpler to weigh the solid lead nitrate than to weigh the gaseous nitrogen dioxide.

A 46-liter annealed glass carboy was fitted for preparing mixtures of the test gases (Figure 1). It was placed inside a cardboard container for insulation against heat loss, in order to minimize the condensation of nitrogen dioxide on the carboy. A single weighed crystal of lead nitrate was placed between two glass wool plugs in a charging tube, which had a stopcock attached to one end. The charging tube was then fitted into place, as shown in Figure 1, and the stopcock closed. With the long mixing and air inlet tube closed by means of a pinch cock over the rubber tube connected to the glass sleeve, the carboy was evacuated to approximately 20 cm Hg below atmospheric pressure. The evacuation tube was closed with a pinch cock, and the vacuum pump disconnected. Heat was applied to the charging tube near the lead nitrate crystal with a Tirrill burner until the brown gas, nitrogen dioxide, was visible in the charging tube. The charging tube stopcock was opened momentarily and then closed, so that air could sweep the nitrogen dioxide from the charging tube into the carboy. The heating of the lead nitrate and the sweeping of nitrogen dioxide into the carboy was repeated three times after visible nitrogen dioxide could no longer be produced by heating. Pressure inside the carboy was then adjusted to atmospheric pressure and the stirring tube was loosened from the glass sleeve, so that it could be turned inside the carboy. The polyethylene bag, which was tied over the opening in the end of the mixing tube, gave a propeller-like action when it was turned.

Three minutes of rapid stirring gave a satisfactory mixing of the nitrogen dioxide and air in the carboy. The rubber tube on the end of the stirring and air-inlet tube was then pulled down over the glass sleeve and left open at the top so that the inside of the polyethylene bag was connected directly to the outside air. As a result, when samples were withdrawn from the carboy, the pressure inside the carboy was equalized by air from the outside filling the bag, without diluting the prepared mixture. To minimize adsorption of nitrogen dioxide on the carboy and plastic bag, all sampling was completed as soon as feasible, always within an hour after sample preparation.

To prepare known concentrations of nitric ox-

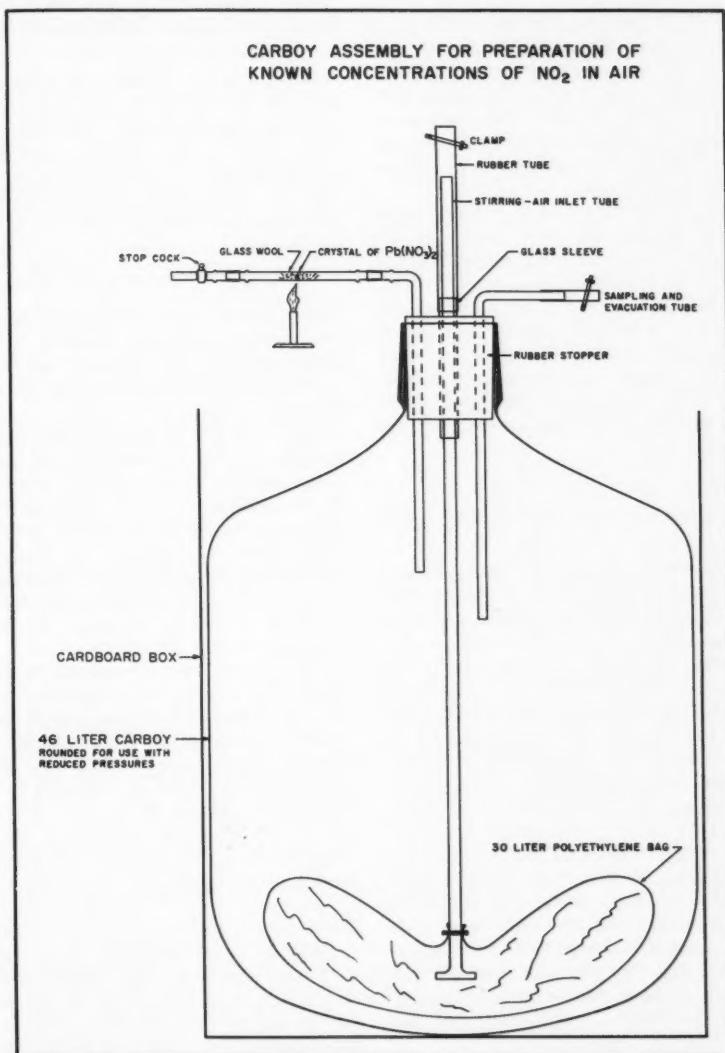


FIGURE 1.

ide which would remain stable in the test carboy long enough for adequate sampling, it was necessary to reduce the oxygen concentration in the carboy. By inflating the 30 liter polyethylene bag in the carboy, approximately two-thirds of the air in the carboy was forced out. Nitrogen under pressure was then passed into the carboy so that the air was forced back out of the bag. By alternately removing two-thirds of the air in the carboy and diluting the remainder with a volume of nitrogen equal to two-thirds the carboy volume,

the 20 per cent oxygen in the air was reduced in five exchanges to approximately 0.08 per cent. With this reduced oxygen concentration, the oxidation of nitric oxide to nitrogen dioxide was negligible.

Elkins<sup>7</sup> states that

$$\frac{dc(\text{NO}_2)}{dt} = 14.8 \times 10^9 \times c_{\text{O}_2} \times c_{\text{NO}}^2,$$

if the concentrations are in mols per cc, and if the time is in seconds. Substituting the concen-

trations of NO at 200 ppm, and O<sub>2</sub> at 800 ppm, the concentration of NO<sub>2</sub> after 30 minutes was calculated to be 0.2 ppm, which is negligible for this purpose.) The carboy was again partially evacuated, and a measured volume of nitrogen dioxide was drawn from a syringe into the carboy, followed by nitrogen until atmospheric pressure was reached.

If an atmosphere containing both nitric oxide and nitrogen dioxide was to be made up, the nitrogen dioxide was charged first by thermal decomposition of a weighed sample of lead nitrate using nitrogen instead of air to sweep the nitrogen dioxide into the carboy, and subsequently drawing a measured volume of nitric oxide into the carboy. Various known concentrations of nitric oxide alone and mixtures of nitric oxide and nitrogen dioxide were prepared in this manner.

*Phenoldisulfonic Acid Method for the Determination of Nitrogen Dioxide and Nitric Oxide*

Air samples were collected in 500-ml evacuated flasks containing 10 ml of absorbing solution. After standing for two hours to allow complete absorption of the oxides, the solution was transferred to a beaker or casserole. It was then neutralized with KOH solution and evaporated just to dryness on a steam bath. The sample was cooled and then dissolved in 2 ml of phenoldisulfonic acid, warming it as necessary to effect complete solution. The solution was again cooled, diluted with 30 ml of water, and then 20 ml of 1:1 ammonium hydroxide was added. When necessary, the solution was filtered, otherwise, it was transferred directly to a 100-ml volumetric flask and diluted to volume. The intensity of the color was determined in a Beckman Model DU spectrophotometer at 410 m $\mu$ . The oxides of nitrogen were determined as nitrogen dioxide from a standard curve, and atmospheric concentrations were calculated in ppm (by volume).

In another application of the phenoldisulfonic acid method, a silica gel tube was attached to an evacuated flask in such a manner that the air sample was passed through the silica gel into the flask. The nitrogen dioxide which collected on the silica gel, and the nitrogen dioxide and nitric oxide which passed into the flask, were determined separately by the phenoldisulfonic acid method.<sup>2</sup> Using a known percentage adsorption of nitrogen dioxide on the silica gel, total nitrogen dioxide was calculated and the nitric oxide determined by difference.

*Nitrite Methods of Nitrogen Dioxide Determination*

Because of the time required for the phenoldisulfonic acid analysis, other more rapid methods have been proposed. The most notable of these methods is a modification of one used by the British,<sup>3</sup> in which the Griess-Ilosvay reagent is used to measure the nitrite formed when nitrogen dioxide dissolves in water, according to the equation:



This involves the diazotization of sulfanilic acid with nitrous acid and coupling with 1-naphthylamine to produce a pink color, the intensity of which is proportional to the nitrite concentration.

Patty and Petty<sup>3</sup> adapted the Griess-Ilosvay reaction to the determination of nitrogen dioxide in air by using a 50-ml syringe containing 10 ml of the aqueous nitrite reagent. A rubber policeman was used as a cap to replace the needle adapter. Fifty ml of air sample was drawn into the syringe and the syringe shaken several times. To determine the concentration of nitrogen oxides, the color developed after five minutes was compared to color standards prepared from known concentrations of sodium nitrite. By varying the volume of the reagent and the volume of the air sample collected, a useful sampling range from 1 to 500 ppm was obtained. Patty and Petty found that instead of 50 per cent nitrite, as indicated by the equation, they obtained an average of 57 per cent nitrite, assuming 100 per cent to be the value obtained if all the nitrogen dioxide had become nitrite. Absorbance was measured at 510 m $\mu$ .

Jacobs and Brodey<sup>5</sup> modified the method of Patty and Petty by using N-(1-naphthyl) ethylenediamine dihydrochloride with sulfanilimide and tartaric acid as a dry reagent mix. One mg of this dry mix was placed inside the syringe, and 10 ml of water added to produce the aqueous reagent. Advantages stated for this method were that the dry reagent remained stable for as long as a year, and the color developed was stable for several hours. Standards were prepared from sodium nitrite in the same manner that the Patty and Petty standards were prepared. The absorbance was measured in a spectrophotometer at a wavelength of 540 m $\mu$ .

Saltzman<sup>6</sup> investigated several reagents and reported that a mixture of sulfanilic acid, N-(1-naphthyl) ethylenediamine dihydrochloride and acetic acid was the most sensitive and gave the best results with respect to absorption of

nitrogen dioxide. Color development was reported complete within 15 minutes, and it was stated that the reagent was specific for nitrogen dioxide and did not absorb nitric oxide. The absorbance was measured in a spectrophotometer at 550 m $\mu$ .

*Method for Determining the Effect of Nitric Oxide on Nitrite Reagents*

It was observed that definite color changes occurred when 98 per cent nitric oxide (Matheson Co., East Rutherford, N. J.) was bubbled through nitrite reagent C.\* The following tests were made to obtain quantitative data.

Mixtures of nitrogen dioxide and nitric oxide in nitrogen, and mixtures of nitric oxide in nitrogen were prepared in the test carboy. Samples were collected in 50-ml syringes, using 15 ml of reagent B in one set, and 15 ml of reagent C in a second set. Absorption and color development were allowed to continue for two hours and the color intensities were then measured in a spectrophotometer. Results were reported in parts per million nitrogen dioxide from a standard curve prepared from known concentrations of nitrogen dioxide in air.

**Results**

*Determination of Nitrogen Dioxide by the Phenoldisulfonic Acid Method*

Table I present data from a number of analyses by this method. These results show good recoveries in the range above 16 ppm, and only fair results in concentrations below 16 ppm.

*Silica Gel Adsorption of Nitrogen Dioxide and Nitric Oxide*

Previous work has indicated that a specific fraction of nitrogen dioxide could be collected on silica gel. A high blank value, equivalent to about 100 ppm of nitrogen dioxide, was found when 8 grams of 6-16 mesh non-acid-washed silica gel was used, which made the determination of nitrogen dioxide in low concentration uncertain. Use of adsorption tubes containing 4 grams of 12-20 mesh acid washed silica gel reduced the blank to the equivalent of about 8 ppm.

Additional tests have been performed to determine the adsorption characteristics of the 12-20 mesh acid washed silica gel. Results are shown in Tables II and III. In concentrations as high as 120 ppm nitrogen dioxide, approximately 40 per cent is adsorbed by the silica

TABLE I  
Determination of Known Concentrations of Nitrogen Dioxide in Air by the Phenoldisulphonic Acid Method

NO <sub>2</sub> , taken*	ppm found**	Recovery per cent	Standard deviation
2.9	4.4	152	1.1
3.6	4.0	114	0.3
6.6	6.5	101	2.0
9.0	11.0	123	1.7
16	16.3	104	1.6
18	16.9	94	1.7
22	22.2	102	1.4
48	44.0	95	3.4
64	62.0	97	2.9
79	71.7	91	4.1
116	106	92	4.8
135	127	95	9.3
146	133	91	5.1
151	140	92	3.6
165	156	95	8.0
185	183	98	6.4
334	313	94	4.2
503	493	98	18.6
700	634	91	7.5
1260	1205	96	23.0

\* Calculated from weights of Pb(NO<sub>2</sub>)<sub>2</sub>; may vary  $\pm 0.3$  ppm.

\*\* Average of 4 to 6 samples.

TABLE II  
Adsorption of Nitrogen Dioxide by Four Grams 12-20 Mesh Silica Gel (Average of 3 Samples)

NO <sub>2</sub> Taken* ppm	NO <sub>2</sub> adsorbed** Per Cent	Standard Deviation
15.5	42	1.6
23.4	38	1.7
46.0	42	0.9
59.0	40	0.6
116	42	3.8
682	53	21.0
2260	67	112.0
5720	65	141.0

\* Calculated from weights of Pb(NO<sub>2</sub>)<sub>2</sub>; may vary  $\pm 0.3$  ppm.

\*\* Average of 3 samples.

TABLE III  
Adsorption of Nitrogen Dioxide and Nitric Oxide on Silica Gel in an Atmosphere of Nitrogen

NO <sub>2</sub> ppm	NO <sub>x</sub> ppm	NO <sub>2</sub> adsorbed* per cent	Standard deviation
none	214	1.6	2.4
75	107	40.0	3.8
84	214	65.0	7.0

\* Average of 3 samples.

gel. At higher concentrations, the adsorption increases to approximately 65 per cent.

In concentrations as high as 200 ppm nitric oxide, 12-20 mesh silica gel adsorbs no more than approximately one per cent of nitric oxide. In mixtures of as much as 75 ppm nitrogen dioxide and 107 ppm nitric oxide, there is no indication of adsorption of nitric oxide. However, a mixture of 84 ppm nitrogen dioxide and 214 ppm nitric oxide shows 65 per cent adsorption of nitrogen dioxide, which is about 25 per cent higher than with the same concentration of pure nitrogen dioxide (Table II). This may indicate some adsorption of nitric oxide by silica gel. Daniels<sup>8</sup> and associates have patented a process for the recovery of nitric oxide by adsorption on nitrogen dioxide-saturated silica gel, where the nitric oxide is catalytically oxidized to nitrogen dioxide. It may be that adsorption and catalytic oxidation of nitric oxide occurs when the concentrations of nitrogen dioxide and nitric oxide exceeds about 100 or 200 ppm respectively.

#### Determination of $\text{NO}_2$ by Nitrite Reagents

Using a 50-ml syringe for the determination of known concentrations of nitrogen dioxide, data have been obtained on the recovery of nitrogen dioxide with nitrite reagents A<sup>5</sup>, B<sup>5</sup>, and C<sup>4</sup>. Ten ml of reagent were used in each determination, with shaking 100 times, and allowing 15 minutes for color development.

The color developed by the reaction between nitrogen dioxide and the aqueous reagents was determined by reading the color intensity of

TABLE IV  
Nitrite Produced by Solution of Nitrogen Dioxide  
in Aqueous Reagents

Nitrite Reagent A			Nitrite agent B			Nitrite Reagent C		
$\text{NO}_2$ , ppm	Nitrite, per cent*	Standard deviation	$\text{NO}_2$ , ppm	Nitrite, per cent*	Standard deviation	$\text{NO}_2$ , ppm	Nitrite, per cent*	Standard deviation
40	61	8.0	5	54.6	4.0	5.5	69.5	2.9
73	63	3.4	11.1	49.7	5.8	33.7	55.6	2.4
95	54	10.6	19.1	63.9	3.2	64.1	66.0	3.1
100	55	6.8	48.2	68.2	3.4	67.5	52.1	1.4
218	52	9.7	78.7	44.0	2.3	135.0	55.8	2.2
512	43	2.5	107.0	78.0	3.3	185.0	60.1	1.4
—	—	—	332.0	65.3	1.0	334.0	57.9	2.4
—	—	—	700.0	71.0	1.0	1260.0	57.1	2.2
Avg. = 55.3 $\pm$ 14 per cent			Avg. = 63.2 $\pm$ 19 per cent			Avg. = 58.1 $\pm$ 8.5 per cent		

\* Average of four to six samples.

the sample in the spectrophotometer and obtaining the nitrite concentration from a standard nitrite curve prepared from sodium nitrite. An empirical relationship between the nitrite produced by nitrogen dioxide reacting with the aqueous reagent and the nitrogen dioxide present in the air sample, has been reported for each of the nitrite reagents. This relationship is reported in terms of the percentage of nitrogen dioxide which becomes nitrous acid (nitrite) when the nitrogen dioxide dissolves in the aqueous reagent.

The results of determination of nitrogen dioxide as nitrite as shown in Table IV indicate that the nitrite reagents A and B approximate the 57 per cent recovery claimed for these reagents.<sup>3, 5</sup> The recovery for the nitrite reagent C at 58 per cent is somewhat lower than the 72 per cent stated in the literature.<sup>4</sup>

During the determination of nitrogen dioxide samples as nitrite, nitrite concentrations continued to increase over a period of several hours. Furthermore it was necessary to use an exact color development time in order to get consistent results. Since the literature had indicated that color development was complete within 15 minutes,<sup>3, 4, 5</sup> it was considered desirable to know more fully the characteristics of color development resulting from the reaction between nitrogen dioxide and the Griess-Ilosvay type nitrite reagents.

The color development time for each of the nitrite reagents with known concentrations of sodium nitrite are plotted in Figure 2. The data show that color development for nitrite ions reacting with Griess-Ilosvay type nitrite reagents is complete within 15 minutes. It seemed probable that the continuing color development, observed in nitrogen dioxide samples collected in 50-ml syringes, was due to the additional time required for nitrogen dioxide molecules to diffuse into the absorbing reagent.

Because samples collected in the field might not be determined in the laboratory for several hours, it was important to know what changes in findings might result from continued color development. To determine the relationship between time and color development for nitrogen dioxide in syringes with nitrite reagents, samples of nitrogen dioxide were collected in this manner at concentrations of 80 ppm and 270 ppm nitrogen dioxide. Nitrite concentrations were determined at intervals over a period of several hours. Results are shown in Figures 3 and 4. Color development was rapid for a period of about one hour, and then continued more slowly over a period of several hours.

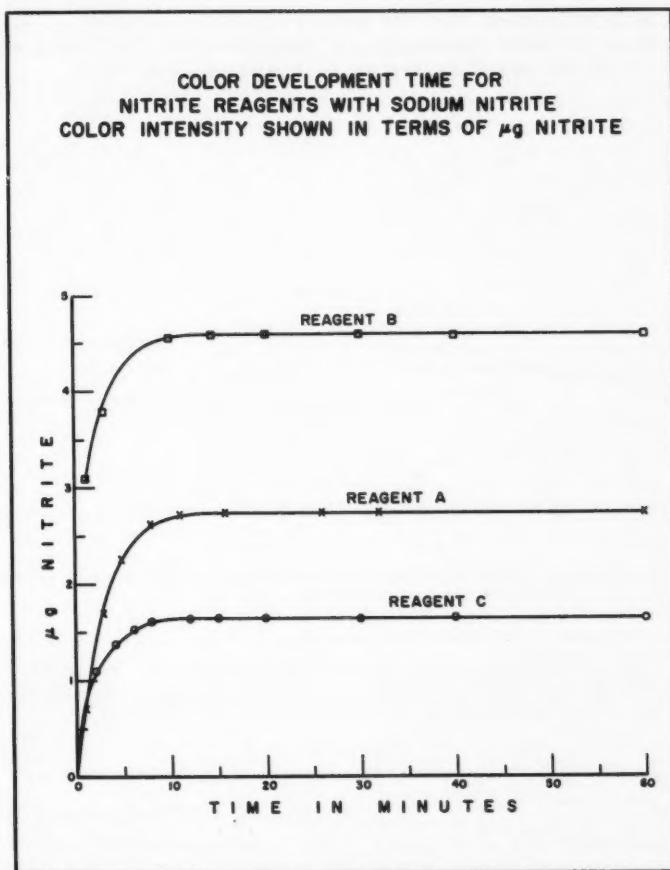


FIGURE 2.

These results indicate that greatest accuracy would be obtained by taking color intensity readings after the period of rapid color development had been completed. Accurate determination of field samples might be done in the laboratory hours after collection if they had been protected from excessive heat and light. Also, greatest sensitivity was shown by nitrite reagents B and C.

#### *Effects of Environmental Conditions on Nitrite Reagents*

Field tests are frequently made at elevated temperatures in the bright sunshine. The effects of these environmental conditions were investigated to provide a better understanding of actual effects.

#### *Determination of High Concentrations of Nitrogen Dioxide with Nitrite Reagents by Dilution*

At higher concentrations of nitrogen dioxide the color produced in the reaction with nitrite reagents may be outside the range of the spectrophotometer. Results of determinations based on 1 to 10 dilution of the developed sample with additional reagent are shown in Table VII. Approximately 100 per cent recoveries may be obtained by this technique.

#### *Effect of Nitric Oxide on Nitrite Reagents*

It has been stated that nitrite reagents are specific for nitrogen dioxide and do not react with nitric oxide. The basis for this statement is the work of Shnidman and Yeaw<sup>9</sup> who worked

COLOR DEVELOPMENT TIME FOR NITRITE REAGENTS WITH 80 ppm NO<sub>2</sub>  
USING 50 ml SYRINGES CONTAINING 15 ml REAGENT & 20 ml OF GAS SAMPLE  
COLOR INTENSITY SHOWN IN TERMS OF  $\mu$ g NITRITE

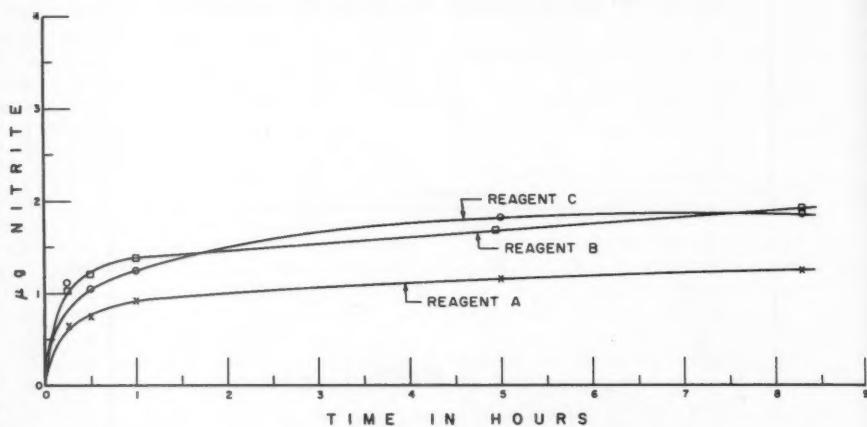


FIGURE 3.

COLOR DEVELOPMENT TIME FOR NITRITE REAGENTS WITH 270 ppm NO<sub>2</sub>  
USING 50 ml SYRINGES CONTAINING 15 ml REAGENT & 35 ml OF GAS SAMPLE  
COLOR INTENSITY SHOWN IN TERMS OF  $\mu$ g NITRITE

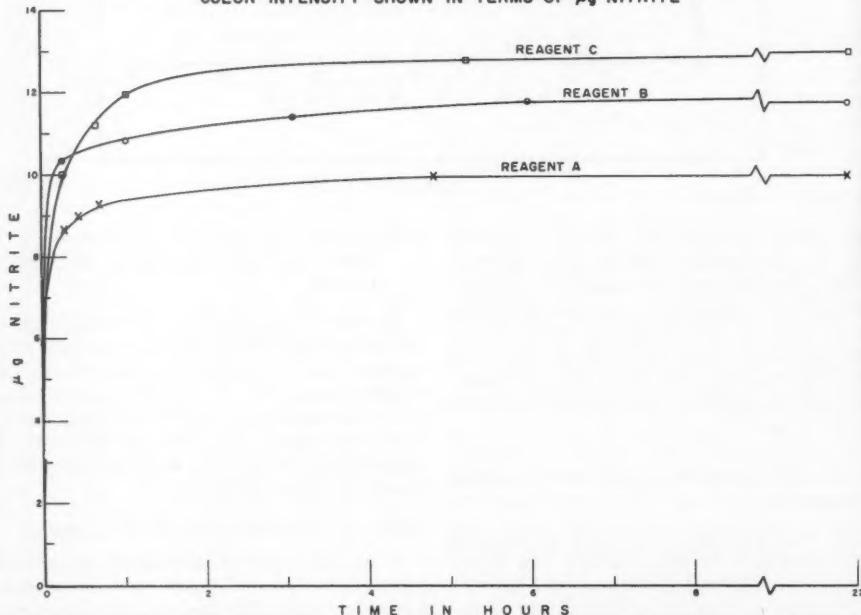


FIGURE 4.

TABLE V  
Effect of Temperature and Sunlight\*

Nitrite reagent	Effect of temperature; change in nitrite concentration after 4 hours		Effect of sunlight at approximately 90°F.; change in nitrite concentration after 4 hours
	95°F	104°F	
A	-20%	-97%	-20%
B	+10%	+15%	+23%
C	+10%	+ 8%	+12%

\* Samples were compared to control samples that were unexposed.

TABLE VI  
Effect of Aging\* on Reagent

Nitrite reagent	Aging time, days	NO <sub>2</sub> , ppm		
		Fresh	Aged	% Loss
B	30 L	115	93	19
	7 L	154	143	8
	7 R	154	146	5
C	9 L	75	56	25
	9 R			
	7 L	148	119	18
	7 R	148	125	15

\* Reagent A was not included because its use is limited to the freshly prepared reagent.

L—in laboratory

R—in refrigerator

with 1 to 2 ppm, using the Ilosvay reagent, herein referred to as nitrite reagent A.

In a qualitative test, a single bubble of nitric oxide produced a rapid color change similar to that produced by nitrogen dioxide in a flask filled with nitrite reagent. Inasmuch as the work reported in this paper is concerned with higher concentrations of nitric oxide than those studied by Shnidman and Yeaw, an effort has been made to demonstrate the effect of nitric oxide on the nitrite reagents in such concentrations.

Test results in Table VIII show substantial concentrations of nitric oxide recovered by the nitrite reagent. While this may be due in part to dissolved oxygen reacting with the nitric oxide to produce nitrogen dioxide, the situation is typical of field and laboratory sampling with nitrite reagents. It appears that nitric oxide does produce nitrite in the reagent used for determining nitrogen dioxide as nitrite. Percentage recovery of nitric oxide may be higher in higher concentrations of nitric oxide.

TABLE VII  
Effect of Dilution on Recovery of Nitrogen Dioxide as Nitrite

NO <sub>2</sub> , ppm	Recovery after dilution per cent		
	Reagent A	Reagent B	Reagent C
130	—	95 ± 1%	90 ± 5%
143	99.5 ± 1%	—	—
448	—	104 ± 2%	103 ± 7%

TABLE VIII  
Recovery of Nitric Oxide as Nitrite by Nitrite Reagents B and C, Using Mixtures of Nitrogen Dioxide and Nitric Oxide\* in an Atmosphere of Nitrogen\*\*

NO <sub>2</sub> ppm	NO ppm	Total NO and NO <sub>2</sub> recovered as nitrite, ppm	NO recovered	
			ppm	per cent
177	107	Nitrite Reagent B = 197	20	19
		Nitrite Reagent C = 228	50	47
94	100	Nitrite Reagent B = 115	20	20
		Nitrite Reagent C = 133	40	40
0	214	Nitrite Reagent B = 102	100	47
		Nitrite Reagent C = 126	126	58

\* Matheson Co., East Rutherford, N. J., 98% NO.

\*\* Matheson Co., East Rutherford, N. J., 99.5% N<sub>2</sub>.

### Summary and Conclusions

A relatively simple method is described for preparing known concentrations of nitrogen dioxide in air. Use of such mixtures makes it feasible to eliminate the use of standard curves based on the empirical and uncertain relationship between metallic nitrite solutions and the nitrite produced by solution of nitrogen dioxide in aqueous reagents.

Determination of atmospheric concentrations of nitrogen dioxide by collection in 500 ml evacuated flasks, and subsequent determination as nitrite by the phenoldisulfonic acid method was accurate and reliable at nitrogen dioxide concentrations above 16 ppm.

Nitrogen dioxide and nitric oxide may be determined separately in mixtures by adsorption of nitrogen dioxide on silica gel. However, it is believed that in cases where the total concentration of such mixtures exceeds 200 ppm, some of the nitric oxide is adsorbed with the nitrogen dioxide, which would make differential analysis of the two gases uncertain.

Nitrogen dioxide may be determined in at-

mospheric samples by collection in 50-ml syringes containing a Griess-Ilosvay type absorbing reagent. Color development occurs rapidly for more than an hour, so that color intensity readings are best made at least an hour after sample collection, and they may be made as much as 24 hours after sample collection.

Results show that Griess-Ilosvay type nitrite reagents are not specific for nitrogen dioxide, as has been stated in the literature, but that they are significantly sensitive to the effects of nitric oxide.

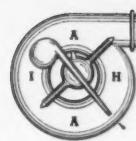
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### INDUSTRIAL NOISE MANUAL

THE *INDUSTRIAL NOISE MANUAL* published by the AIHA Committee on Noise is a book written for industry by specialists from industry. The noise problem is common to all industry, therefore it is important that men of industry, both managerial and technical, be well informed. In ten chapters this Manual covers: Physics of Sound, Instruments for Sound Measurement and Audiometry, How to Measure Sound, How to Make a Sound Survey, Calibration of Equipment, How We Hear, Effects of Noise on Man, Conservation of Hearing, Engineering Controls of Noise, and Personal Protective Equipment.

This publication has received excellent reviews and praise from many sources. Copies are still available for \$7.50 each from American Industrial Hygiene Association, 14125 Prevost, Detroit 27, Michigan. Discounts allowed on quantity orders.



# HYGIENIC GUIDE SERIES

## Magnesium\*

### I. Hygienic Standards

#### A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 15 milligrams (magnesium oxide fume) per cubic meter of air (mg/m<sup>3</sup>).<sup>1</sup>

1. *Basis for Recommendation:* Human studies.

#### B. SEVERITY OF HAZARDS:

1. *Health:* Low for both acute and chronic exposures. Experimental metal fume fever has been produced in man by inhalation of excessive concentrations of the oxide fume from heated magnesium.<sup>2, 3</sup> However, no reports of such conditions occurring industrially have been reported. Although delayed healing and gaseous blebs have been reported<sup>6, 7, 11</sup> as resulting from magnesium slivers when implanted in experimental animals, this has not been a major problem in industrial practice.<sup>5</sup> Experimental work with animals has failed to elicit any detrimental response in the lungs.<sup>4</sup> Magnesium dust is somewhat irritating to mucous membranes.<sup>5</sup>

2. *Fire and Explosion:* Extreme fire and explosion hazard when in powdered or dust form. High fire hazard in the form of turnings or chips where there is a possibility of ignition by outside sources. The ignition temperature of pure magnesium is about 1200°F, but finely divided magnesium alloys may be ignited below 900°F. Molten magnesium will burn in air and must be protected by a suitable flux or by a protective atmosphere such as SO<sub>2</sub>. Molten magnesium reacts violently with hot iron oxide scale and with moisture.<sup>10</sup>

### II. Significant Properties

Magnesium is a light, silvery-white metal and it and its alloys are available commercially in the form of ingot, bar, rod, sheet, plate, extruded shapes, sand and die castings, etc.

Chemical formula:	Mg
Molecular weight:	24.32
Specific gravity:	1.74
Melting point:	1202°F (650°C)
Solubility:	Insoluble in chromic and concentrated hydrofluoric acids and ethyl alcohol.

### III. Industrial Hygiene Practice

A. RECOGNITION: No identifying characteristics of taste, odor, or irritation. Widely used as a light structural metal. Worked industrially by many processes such as sand casting, die casting, forging, extrusion, rolling, machining, grinding, welding, heat treating, etc.

#### B. EVALUATION OF EXPOSURES:

1. *Direct Instrumentation:* None available.
2. *Chemical Method:* Magnesium oxide fume can be determined colorimetrically using Titan Yellow in samples collected by an electrostatic precipitator.<sup>12</sup>

C. RECOMMENDED CONTROL PROCEDURES: Dust production should be controlled with wet-type dust collectors approved for this purpose.<sup>8, 10</sup> Ducts should be short, straight sections with conveniently spaced clean-out doors. Dust collectors should be separate from other ventilation systems. Machining should be performed in the dry state or with high flash neutral mineral oil coolants. Water, water-soluble oils, oils containing more than 0.2 per cent fatty acids and animal or vegetable

\* The Committee wishes to thank V. K. Rowe of Dow Chemical Company for help in reviewing the manuscript for this Hygienic Guide.

oils should not be used. Chips, turnings and other magnesium fines should be collected in pans and removed as frequently as necessary (at least on a daily basis) to prevent accumulation of large amounts. Magnesium fines should be placed in covered, plainly labeled, clean, dry steel containers and stored in a detached scrap storage building or in a special fire-resistant storage room. Storage areas should have explosion vents equivalent to thin glass windows that are at least equal in area to one square foot for each 15 cubic feet of room volume. Magnesium scrap which is to be recovered should be kept dry and free of foreign matter. Magnesium scrap which is not to be salvaged should be burned in an approved manner.<sup>8, 10</sup>

All tools as well as any material to be added to melting pots should be thoroughly preheated before immersion into the molten metal.

Buildings used for storage of magnesium should preferably be noncombustible with well drained floors and without basements or depressions. Stock piles of magnesium ingots, billets, pigs, etc., should be separated from other combustible materials, limited in size to 500,000 pounds and preferably not higher than twice the aisle width. Detailed information on storage, handling and processing of magnesium and its alloys is available.<sup>8, 10</sup> Smooth, fire-resistant clothing without pockets, cuffs or other recesses and with nonferrous fasteners should be worn in areas engaged in grinding magnesium. Fire-resistant clothing should be worn while handling the molten metal and in burning scrap. Face shields, and leather gloves should be provided where indicated. Only approved graphite-type (such as G-1 powder) or salt-resin base (such as Met-L-X) extinguishing agents for metallic fires should be used.

Grinding wheels cannot be safely interchanged between use with magnesium and other metals. Grinding wheels for work involving magnesium should be reserved

for this purpose and not used for other metals.<sup>9</sup> Any change from use with magnesium to other metals requires a thorough cleaning of the machine.

#### IV. Specific Procedures

- A. FIRST AID: Eyes should be irrigated by copious amounts of water, followed by medical attention. Magnesium which has penetrated the skin should be completely removed before dressing the wound. Magnesium burns should be treated in the same manner as other thermal burns, after removing magnesium powder or particles.
- B. SPECIAL MEDICAL PROCEDURES: No special requirements for placement appear necessary.

#### V. References

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## Nitroglycerin\*

### (Glycerol trinitrate)

#### I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 0.5 parts per million parts of air, by volume (ppm).<sup>1</sup>

1. *Basis for Recommendation:* Limited observation on humans.

B. SEVERITY OF HAZARDS:

1. *Health:* High for acute exposure, moderate for chronic exposure. Chief effect is the dilatation of the blood vessels—for which purpose nitroglycerin is used as a drug in the treatment of angina pectoris. Absorption of small amounts results in a characteristic throbbing headache. If larger amounts are absorbed, nausea, vomiting, and methemoglobinemia with cyanosis may occur—also marked fall in blood pressure, central nervous system depression, coma, and respiratory paralysis. There is a marked intolerance to alcohol. Fatalities from industrial intoxication are not common but some have been reported.<sup>2</sup> In some instances, there was exposure to nitroglycerin as well as nitroglycerin. A temporary tolerance to headache is developed among exposed workers, which is usually lost after a few days without exposure. Medical studies of nitroglycerin workers have failed to reveal significant findings.<sup>3</sup> The exposures involved, however, while sufficient to produce headaches and other transient symptoms, were near or below the MAC.
2. *Fire and Explosion:* Extra hazardous. Explodes violently upon shock and when heated. Sensitivity to shock and flame is reduced by admixture with inert materials, as in dynamite.
- C. SHORT EXPOSURE TOLERANCE: Not known. The minimum effective dose by cutaneous absorption is 10 to 18 mg.
- D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Not known. Because of low vapor pressure (air saturated with vapor of nitroglycerin at 20°C would contain approximately 0.33 ppm) such concentrations of vapor are im-

probable in industrial practice. However, most dynamite manufacturing practices today involve the use of ethylene glycol dinitrate with the nitroglycerin. Exposure to vapor from such mixtures is predominantly due to ethylene glycol dinitrate vapor, since its vapor pressure is more than one hundred times that of nitroglycerin. The minimum lethal dose of nitroglycerin is reportedly about 200 mg.<sup>4</sup>

#### II. Significant Properties

Nitroglycerin is a colorless, oily liquid. When heated to about 260°C, it explodes violently.

Chemical formula:	$C_3H_5(ONO_2)_3$
Molecular weight:	227.1
Specific gravity:	1.601
Melting point:	13°C
Vapor pressure:	0.00025 mm Hg at 20°C
Relative vapor density:	7.8 (air = 1)
Solubility:	slightly soluble in water; partly soluble in alcohol; miscible with ether and chloroform
At 25°C and 760 mm Hg:	
1 ppm of vapor =	0.0093 mg/liter
1 mg/liter of vapor =	108 ppm

#### III. Industrial Hygiene Practice

A. RECOGNITION: Used in explosives, such as dynamite, cordite and blasting gelatin, and in pharmaceuticals as a vasodilator.

B. EVALUATION OF EXPOSURE:

1. *Direct Instrumentation:* None.
2. *Chemical Method:* Absorption in alcohol followed by hydrolysis and determination of nitrate by any suitable method. An alternate method which may be preferable is to absorb in distilled water followed by determination of the nitrate with diphenylbenzidine.<sup>5</sup>

C. RECOMMENDED CONTROL PROCEDURES: Good ventilation should be supplied to keep the concentration of nitroglycerin vapor at low levels. Strict precautions should be taken to prevent skin contact

\* The Committee wishes to express its appreciation to Dr. John Zapp and Dr. Boyd Shaffer for their careful review of this Hygienic Guide.

with the liquid or dust. Frequent changes of suitable protective clothing are important. Canvas gloves are preferable to rubber if changed frequently, since rubber tends to absorb and retain nitroglycerin. Stringent precautions against fire and explosion must be maintained.

#### IV. Specific Procedures

- A. **FIRST AID:** Mild headaches may be relieved by aspirin; oxygen inhalation may be helpful in headaches due to methemoglobin. Alcohol is contraindicated. Remove from skin by scrubbing with soap and water.
- B. **SPECIAL MEDICAL PROCEDURES:** Individuals with significant cardiovascular abnormalities should not work with nitroglycerin. Alcoholics should not be exposed, even moderate drinkers should be warned of the possible aggravating effects of alcohol consumption.<sup>5</sup>

#### V. References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. Ind. Health* 20: 266 (1959).
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## Metal Hydrides\*

### (Primary Types)

Metal Hydrides chemically can be divided into two groups, primary and complex. This Guide considers only the primary group and includes the hydrides of sodium, potassium, lithium, magnesium, calcium and strontium.

#### I. Hygienic Standards

- A. **RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours):** A tentative value of 25 micrograms/cubic meter has been suggested for lithium hydride.<sup>1</sup> The toxicity of these hydrides depends on the metallic portion of the compound.<sup>2</sup>
- B. **SEVERITY OF HAZARDS:**
  1. **Health:** Moderate. No studies reported to evaluate the health hazards of the alkali hydrides. Moisture from the body will convert these hydrides into caustic hydroxides. The hydrides are therefore irritating to the skin, eyes and mucous membranes of the nose, throat and lungs. In addition, there is a large amount of heat released from the reaction of the hydrides with the moisture of the skin.<sup>2</sup>

2. **Fire:** Although some hydrides are difficult to ignite, once ignited they cannot be extinguished by ordinary means. Smothering with dry sand, ground dolomite, graphite or commercial dry powder extinguishing agents for metal fires is the most effective. Best control of powder fires is obtained by spreading the extinguishant on by hand. Do not use a pressurized extinguisher. *Do not* use water, carbon tetrachloride or carbon dioxide fire extinguishers. Primary hydrides may be divided into two groups according to their degree of reaction with water.<sup>3</sup> In the one group are those hydrides which may be ignited, and frequently explode when in contact with water or large concentrations of water vapor. Sodium and potassium hydride belong to this group; potassium hydride is more reactive than sodium hydride with water. Another group consists of hydrides that generally do not ignite but do react with water. This group contains lithium, calcium, and strontium. The large volume of hydrogen liberated when hydrides react with water causes the greatest problem.

\* The Committee wishes to express its thanks to Dr. M. D. Banus of Metal Hydrides, Inc., for reviewing this Hygienic Guide and for making valuable suggestions.

The hydrogen has to be vented satisfactorily and isolated from sparks, flames or other means of ignition.<sup>2</sup> Dusts of hydrides are inflammable and can be ignited by sparks, static sparks or open flames.

C. SHORT EXPOSURE TOLERANCE: Not known.  
 D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Not known.

## II. Significant Properties

### *Lithium Hydride*

Colorless, crystalline solid  
 Chemical formula: LiH  
 Molecular weight: 7.95  
 Specific gravity: 0.82  
 Melting point: 680°C

### *Sodium Hydride*

White, crystalline solid  
 Chemical formula: NaH  
 Molecular weight: 24  
 Specific gravity: 1.4  
 Melting point: undetermined, because of dissociation

### *Potassium Hydride*

White, crystalline solid  
 Chemical formula: KH  
 Molecular weight: 40.1  
 Specific gravity: 1.43  
 Melting point: undetermined, because of dissociation

### *Calcium Hydride*

Gray-white, crystalline solid  
 Chemical formula: CaH<sub>2</sub>  
 Molecular weight: 42.1  
 Specific gravity: 1.9  
 Melting point: over 1000°C

### *Strontrium Hydride*

Crystalline solid  
 Chemical formula: SrH<sub>2</sub>  
 Molecular weight: 88.6  
 Specific gravity: 3.7  
 Melting point: undetermined

### *Magnesium Hydride*

Gray-white, crystalline solid  
 Chemical formula: MgH<sub>2</sub>  
 Molecular weight: 26.3  
 Specific gravity: 1.4  
 Melting point: undetermined, because of dissociation

## III. Industrial Hygiene Practice

A. RECOGNITION: These hydrides are generally employed in electronic tube

manufacture, ceramics, powdered metal fabrication, metal cleaning and alloy formulating, and in chemical syntheses. The primary irritant effects on the nose and throat are readily recognized in operations giving rise to dust or fume.

B. EVALUATION OF EXPOSURES:  
 1. *Direct Instrumentation:* None.  
 2. *Chemical:* Methods available for detection of the parent metals of the hydrides are the most applicable for hydrides. In general, a dilute acid sampling solution may be used for collecting air samples. Water may also be used as a collection medium. Calcium may be determined as the oxalate, sodium as the magnesium or zinc uranyl acetate complex and potassium as the cobaltinitrite.<sup>4, 5, 6</sup> Flame photometry or spectrographic analyses are applicable.

C. RECOMMENDED CONTROL PROCEDURES: Hydrides can be handled safely if adequate precautions, combined with careful engineering and process development, are employed. Chief hazards in handling powdered hydrides are dusting and fuming, static electricity and fires. These materials, whether in large or small quantity, should be stored in a dry, fire- and explosion-proof room, or for a small quantity, in a locked steel cabinet. During usage, these materials should be protected from moisture (to prevent hydrogen evolution leading to a possible explosion), static electricity, and open flames, as well as nonexplosion-proof motors and equipment. Containers from which sodium hydride has been removed should be taken to a safe disposal area, generally outdoors, and allowed to be exposed to the weather approximately 24 hours before being cleaned and then flushed with kerosene. The container can then be washed with water. Absorbents for spillage should be removed quickly to the disposal area. Personnel should be issued fire-resistant coveralls (using resistant cloth such as Dynel), hard hat with flash mask, safety goggles, respirator approved for caustic dusts, caustic-resistant gauntlet gloves, and appropriate safety shoes. Facilities for flushing skin and eyes with water should be available in convenient, well-marked locations.

## IV. Specific Procedures

A. FIRST AID: Eyes should be irrigated with large amounts of water for 15 minutes.

Get medical attention at once. If ingested, swallow water and milk to dilute; do not attempt to induce vomiting. Call a physician. If powdered material has contacted the skin, the loose material should be brushed off with a dry, non-flammable material such as dolomite before entering a shower. A deluge type of shower using plenty of water is desirable.

B. SPECIAL MEDICAL PROCEDURES: No special requirements for placement appear necessary. All medical personnel should be familiar with the hazards and be quickly available in case of accidents, especially those involving the eyes, nose or throat.

#### V. References

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## Molybdenum

#### I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 5 milligrams of molybdenum per cubic meter of air for soluble compounds; 15 milligrams per cubic meter for insoluble compounds, based primarily on animal data.<sup>1</sup> An opinion<sup>2</sup> has been expressed that slight toxic effects may result from exposure to the soluble compounds at the above level.

B. SEVERITY OF HAZARDS:

1. **Health:** Moderate to low. Acute or chronic poisoning of occupational origin has not been described. Cattle ingesting abnormally high concentrations of molybdenum (20-100  $\mu\text{g}$  Mo/gm dry matter) have been observed to develop a condition known as "teart" marked by severe diarrhea, debilitation, and fading of color of hair.<sup>3</sup> These symptoms may be the result of interference with copper metabolism. Molybdenum is considered an essential trace element in plants, some bacteria, and possibly in mammals. The total body content in normal adult humans is said to be of the order of 20 milligrams, and urinary excretion about 10-20 micrograms/liter.<sup>4</sup> Guinea pigs exposed to 200 mg/m<sup>3</sup> of molybdenum trioxide dust (expressed as molybdenum) for one hour daily, five times per week for five weeks showed evidence of nasal irritation, diarrhea, loss of weight, and muscular incoordination. Exposure to molybdenite ore dust (MoS<sub>2</sub>) at a concentration of 280 mg/m<sup>3</sup> (of molybdenum) on the other hand caused little effect. Fume from arcing molybdenum metal caused some mortality at 190 mg/m<sup>3</sup> but little effect at 53 mg/m<sup>3</sup>. The pathological findings in these experiments were not striking and were limited to bronchial and alveolar irritation with moderate fatty changes in liver and kidneys.<sup>5</sup>
2. **Fire:** None.
3. **SHORT EXPOSURE TOLERANCE:** Not known.
4. **ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE:** Not known, but probably not immediately hazardous to life at any concentration.

#### II. Significant Properties

Dark gray or black powder with metallic luster or coherent mass of silver-white color. Chemical symbol: Mo  
 Atomic weight: 95.95  
 Specific gravity: 10.2  
 Melting point: 2,620°C  $\pm$  10  
 Boiling point: 3,700°C

Solubility: In hot nitric and sulfuric acids

### III. Industrial Hygiene Practice

A. **RECOGNITION:** Used in the form of ferromolybdenum for manufacturing steels; in the manufacture of electrical contacts, spark plugs, x-ray tubes, screens and grids for radio tubes; as a component of certain catalysts used in petroleum refining and chemical processes. Molybdenum sulfide is used as a lubricant.

B. **EVALUATION OF EXPOSURE:**

1. *Direct Instrumentation:* None.
2. *Chemical Method:* Collection of fumes or dust with electrostatic precipitator, filter or impinger followed by conversion to molybdenum trioxide, reduction and titration with potassium permanganate solution. For biological materials, measurement at 475 millimicrons of the red-orange color formed by reaction of the reduced molybdenum with sodium thiocyanate,<sup>5</sup> or spectrographic analysis.

C. **RECOMMENDED CONTROL PROCEDURES:** Keep atmospheric concentration below acceptable limits by enclosure or ventilation. Respiratory protective equipment should be used if the acceptable limits are exceeded.

### IV. Specific Procedures

- A. **FIRST AID:** No specific measures are indicated.
- B. **SPECIAL MEDICAL PROCEDURES:** While examination of blood or urine for molybdenum content should theoretically be useful for estimating absorption of molybdenum, no human data appears to be available correlating exposure and blood or urine levels. While the hazard appears low, in view of the lack of comprehensive studies on exposed persons, periodic health examinations seem desirable.

### V. References

1. American Conference of Governmental Industrial Hygienists: *AMA Arch. Ind. Health* 20: 266 (1959).
2. SMYTH, H. F., JR.: *Am. Ind. Hyg. Assoc. Quart.* 17: 168 (1956).
3. MARTSON, HEDLEY R.: *Physiol. Rev.* 32: 100 (1952).
4. SCHROEDER, HENRY A.: "Chapter on Trace Metals and Chronic Diseases" in *Advances in Internal Medicine* Vol. 8, p. 259, The Yearbook Publishers, Inc., New York, N. Y. (1956).
5. U. S. Public Health Service: *The Toxicity of Molybdenum*. Public Health Bulletin No. 293, Supt. of Documents, Washington, D. C. (1945).

*Because of space limitations, it is impossible to list all methods of exposure evaluation. The selections have been made on the basis of current usage, reliability, and applicability to the usual industrial type of exposure. Any specific evaluation and/or control problem will involve professional judgment. This can best be done by professional industrial hygiene personnel.*

*Respiratory protective devices are commercially available. Their use, however, should be confined to emergency or intermittent exposures and not relied upon as primary means of hazard control.*

*A relative scale is used for rating the severity of hazards: nil, low, moderate, high, and extra hazardous.*

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## News of Local Sections

### Michigan Section

On January 7, 1960 a party was held to congratulate and honor Frank A. Patty on his retirement. Frank is a well-known and respected industrial hygienist and a long time member of AIHA. Although he says he is retiring we shall not be surprised to see and hear from him at many meetings to come.

The regular meeting of the Section was held January 12th. Dr. O. A. Sanders spoke on the subject, "Pulmonary Dust Diseases."

### Gulf Coast Section

At the November 1959 meeting Mr. John G. Liskow of American Air Filter, Inc., spoke on the topic, "Dust Collection and Ventilation in the Occupational Environment." The February 1960 meeting was held jointly with the Houston Industrial Nurses Association and the program centered about discussions of occupational dermatitis problems.

The Section is extending its plans well into the future. A noise symposium is planned for the spring of 1960 with speakers from the U. S. Public Health Service and other national organizations. A statewide occupational health conference is to be held at the University of Texas in November, 1960. This conference is an annual affair and the topic for this year is industrial hygiene in the construction industry.

### Western New York Section

Featuring as its theme, "Frontiers of Industrial Hygiene," the 1959 fall meeting (October 8) of the Western New York Section was an afternoon session held at Rochester's Sheraton Hotel. Mr. Ernest Mohr of Eastman Kodak Company opened the session with an excellent demonstration coupling a taped sound track of actual industrial noises with the simultaneous projection of colored slides picturing (1) the noise source, and (2) curves illustrating the noise levels before and after source enclosure. Colonel George Knauf of the Occupational Health Research Laboratory, Patrick Air Force Base, Florida, discussed Microwaves and the Health Hazards of Rocketry. Closing the program, Jack C. Radcliffe of the Ford Motor Company and President-Elect of the National AIHA discussed the industrial hygiene program followed in his own company.

Subsequent to the technical session, the members attended a cocktail hour as the guests of

Buffalo's Watson Company and Wheelabrator Corporation. A dinner closed the day's activities and those present were privileged to hear a fine address by Elmer Wheeler, President of the AIHA.

We would like to call attention to the November issue of *AIR CONDITIONING, HEATING AND VENTILATING* magazine. The entire reference section of this issue is devoted to a selection of papers presented at a symposium on Heat in Industry sponsored by the Western New York Section of AIHA and presented in Buffalo in October, 1958.

In the December Newsletter for the Section we announced a vigorous membership campaign in which members can obtain one dollar credit against future dues for each new member they obtain. Attractive membership certificates suitable for framing have been issued to all members. (Note from the Editor: Bless you for the plug for Journal subscriptions by associate members.)

### Chicago Section

Dr. H. Glenn Gardiner gave a talk and showed a motion picture on the subject, "The Cardiac in Industry," at the meeting on November 4, 1959. Forty-three members were present at this meeting.

The regular meeting was not held in December. Rather, the Section joined with its counterparts of the American Society of Safety Engineers and the Association of Casualty Safety Engineers in a gay and festive celebration of the Yuletide. (We understand there were no lost time "accidents"!)

### Philadelphia Section

The Twelfth Delaware Science Symposium was held January 13, 1960 at the Hotel Du Pont in Wilmington, Delaware. The Philadelphia Section AIHA sponsored the Industrial Hygiene Section of the program. Concurrent technical sessions were held for analytical chemistry, biochemistry, chemical engineering, metallurgy, organic chemistry, polymer chemistry, statistics and computers, general, and industrial hygiene. In the evening Dr. Wallace R. Brode spoke on "Development of a Science Policy."

Papers presented at the Industrial Hygiene Section were: "Radiation Hazards Aboard a Guided Missile Cruiser" by W. Johnson, V. H. Kindsvatter and C. C. Shaw; "Some Methods

Used in the Evaluation of Inhalation Toxicity" by J. W. Clayton, P. A. Delaplane and E. E. Hurlbrink; "Some Aspects of Exposing Experimental Animals to Vapors and Gases in Air" by J. F. Treon; "Development of a Freeze-Out Technique and Constant Sampling Rate for the Portable 'Uni-Jet' Air Sampler" by A. L. Linch and R. C. Charsha; and "An Industrial Hygiene Approach to a Serious Toxicity Problem in the Petroleum Industry" by B. G. Crane, R. B. Davis and S. L. Rankin.

#### Personnel Notes

Mr. Harry Schulte and Dr. Leslie Silverman presented papers at the Scientific Conference on the Disposal of Radioactive Wastes held in Monaco. Word from them indicates that for the sake of their profession they are enduring the rigors of this assignment.

Commander G. A. L. Johnson, MSC, USN, has been assigned as Head, Industrial Hygiene Branch, Occupational Medicine Division, Bureau of Medicine and Surgery, Navy Department. He had served for the past five years as Industrial Hygiene Officer on the Staff of the Medical Inspector, Headquarters, Western Sea Frontier, Treasure Island, San Francisco, California.

A. J. Trommershausen has been appointed to the newly established position of Chief Industrial Hygienist for Kaiser Aluminum & Chemical Corporation. He will have his headquarters at Oakland, California, and will be responsible for further development of the corporation's industrial hygiene program.

#### Obituary

H. I. Miller, Jr., Industrial Hygiene Engineer, Lackawanna Plant, Bethlehem Steel Company, Lackawanna, New York, passed away January 17, 1960. An AIHA member since 1949 and current president of the Western New York Section, Herb was graduated from Washington University, St. Louis, Missouri in 1934 and received an M.P.H. from the Harvard School of Public Health in 1937. His professional career included employment as Industrial Hygiene Engineer for the St. Joseph Lead Company, and Catalytic Construction Company. A member of the Reserve Corps of the U. S. Army, he was called to active duty in World War II and served with distinction, the last two years of his service being with the Army Industrial Hygiene Laboratory. Eminently competent, Herb's passing is a great loss to the profession.

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#### COMPLETE SETS OF THE QUARTERLY

IN 1958 THE AMERICAN INDUSTRIAL HYGIENE ASSOCIATION expanded its publication to the present Journal. For eighteen years prior to this the AIHA Quarterly had published technical articles in the field of industrial hygiene. Over these years the Quarterly grew in value and significance to the industrial hygienist. Now a limited number of complete sets of the Quarterly (Volumes 1-18; 1940-1957) have been assembled and attractively bound. The hard binding covered with black Fabrikoid is lettered in gold.

Bound with each set is a cumulative index of the entire series. This index is also available in limited quantity for purchase apart from the entire set.

A few complete sets including the cumulative index are still available for \$250.00 per set. Orders or inquiries should be directed to American Industrial Hygiene Association, 14125 Prevost, Detroit 27, Michigan.

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—DDT	—Methyl Bromide	nate
—Diborane	—Methyl Ethyl Ketone	—Trichloroethylene
—1,2-Dichloroethane	—Methylene Dichloride	—1,1,1-Trichloroethane
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